PATENT ABSTRACTS OF JAPAN

(11)Publication number : 08-316125

(43)Date of publication of application : 29.11.1996

(51)Int.Cl. H01L 21 027
G03F 7 20

(21)Application number : 07-121115

(22)Date of filing : 19.05.1995

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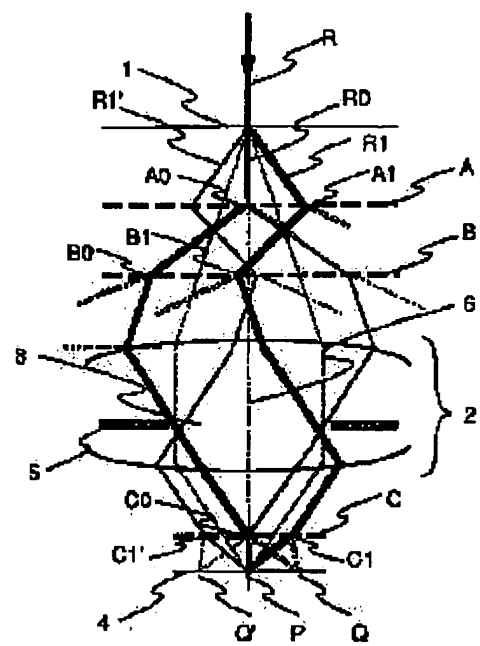
(54) METHOD AND APPARATUS FOR PROJECTION EXPOSING

(57)Abstract:



PURPOSE: To improve the resolution exceeding the diffraction limit by emitting the light from a light source to a mask, diffracting the pattern of the mask, diffracting the diffracted light through a projection optical system, and reproducing the pattern on a sample to be exposed.
CONSTITUTION: A mask 1 is inserted between a projection optical system 2 and diffraction gratings A, B, and a diffraction grating C is inserted between the system 2 and a wafer 4. In this case, the gratings A, B, C are simultaneously phase gratings. The light R perpendicularly incident to the mask 1 is diffracted to zero order diffracted light R0, primary diffraction light R1 and - primary diffracted light R1' on the mask surface. The light R0 arrives at a point A0 on the grating A, and the light diffracted in the - primary direction is diffracted to + primary direction at the point B0 on the grating B. Thereafter, it is diffracted at the point C0 on the grating C via the left end of the pupil 3 in ± primary direction, and arrived at two points Q, P on the image surfaces.

CLAIMS

[Claim(s)
[Claim 1 A projection exposure method comprising a process for which a mask is prepared, a process of irradiating the above-mentioned mask with light from a light source, a process of diffracting a pattern of the above-mentioned mask, and a process of diffracting this diffracted light through a projection optical system, and reproducing and exposing the above-mentioned mask pattern on a sample.
[Claim 2 The projection exposure method according to claim 1 diffracting twice as the above-mentioned process of diffracting.
[Claim 3 A light source, and the 1st and the 2nd diffraction means which irradiate with a pattern on a mask with light from this light source, and diffract light from this mask, A projection aligner consisting of a sample table which lays a sample arranged under a projection optical system which projects diffracted light on a sample, the 3rd diffraction means that diffracts light from this projection optical system, and this 3rd diffraction means.
[Claim 4 The projection aligner according to claim 3, wherein the above 1st and the 2nd diffraction means are phase gratings.
[Claim 5 In a method of forming a pattern on the above-mentioned substrate by irradiating a mask with light of the wavelength lambda which emitted a light source via an illumination-light study system, and carrying out image formation of the pattern on the above-mentioned mask to up to a substrate according to a projection optical system of the numerical aperture NA and the reduction percentage M:1, So that it may have the 1st diffraction grating parallel to the above-mentioned substrate between the above-mentioned substrate and the above-mentioned projection optical system and an image of a mask pattern may be reproduced by interference of light diffracted by said 1st diffraction grating near the substrates face, A projection exposure method providing a diffraction grating, the 2nd diffraction grating and the 3rd diffraction grating, of two sheets sequentially from the above-mentioned mask side between the above-mentioned mask and the above-mentioned illumination-light study system at the above-mentioned mask and parallel.
[Claim 6 The projection exposure method according to claim 5, wherein the interception

spatial frequency f of an optical system which provided said diffraction grating is larger than the interception spatial frequency f0 of an optical system which does not provide said diffraction grating and is f2 or less twice 0.

[Claim 7 The projection exposure method according to claim 5, wherein the space cycle P1 of said 1st diffraction grating is in the range of lambda/(1.42 and NA) < P1 < lambda NA.

[Claim 8 The projection exposure method according to claim 5, wherein period directions of the 1st, 2nd, and 3rd diffraction gratings of the above are equal and the space cycle P1 of the 1st diffraction grating of the above, the space cycle P2 of the 2nd diffraction grating, and the space cycle P3 of the 3rd diffraction grating fill a relation of about 1 P 3 1 P2-1/(M-P1).

[Claim 9 The projection exposure method according to claim 5, wherein the optical distance Z1 and the optical distance Z2 from the above-mentioned mask surface of the 2nd and 3rd diffraction grating of the above, and Z3 fill a relation of P2 (Z3 M Z1, andM) P1 mostly (Z3-Z2) from the above-mentioned substrate face of the 1st diffraction grating of the above.

[Claim 10 Each installed position of the 1st diffraction grating of the above, the 2nd diffraction grating of the above, and the 3rd diffraction grating of the above, Thickness of each transparent substrate which provides the 1st diffraction grating of the above, the 2nd diffraction grating of the above, and the 3rd diffraction grating of the above, And the projection exposure method according to claim 5 setting up a cycle of the 2nd diffraction grating of the above according to physical relationship of NA of said projection optical system and reducing magnification, and each diffraction grating and the above-mentioned substrate so that aberration between the above-mentioned mask surface and the image surface may serve as the minimum.

[Claim 11 the space cycle P2 of said 2nd diffraction grating -- P2 < 1 (1-2 and NA/M) ******** -- the projection exposure method according to claim 5 characterized by things.

[Claim 12 The projection exposure method according to claim 5, wherein said 2nd and 3rd diffraction gratings are phase gratings.

[Claim 13 The projection exposure method according to claim 5, wherein said 1st diffraction grating is a phase grating.

[Claim 14 Width to said one way between said substrate and said 1st diffraction grating by below Z1 and NA. While a space cycle provides the 1st shielding pattern of 2, Z1, and NA mostly,. [whether the 1st shielding pattern of the above on a mask and the 2nd shielding pattern that shades an almost conjugate field are provided right above said mask or in directly under, and an exposure region is restricted to it, and Or the projection exposure method according to claim 5 scanning and exposing on a substrate an exposure region restricted [above-mentioned], or exposing moving to step form.

[Claim 15 The projection exposure method according to claim 5 which said diffraction grating is a one-dimensional diffraction grating, and is characterized by carrying out aberration compensation so that a wavefront aberration of said projection optical system may serve as axial symmetry centering on a diameter of a direction vertical to period

directions of the above-mentioned diffraction grating on a pupil.

[Claim 16 The projection exposure method according to claim 5, wherein said mask contains a cycle type phase shift mask.

[Claim 17 The projection exposure method according to claim 5, wherein said mask has a detailed pattern in a specific direction according to a cycle and a direction of said 1st diffraction grating.

[Claim 18 The projection exposure method according to claim 5, wherein said mask amends pattern shape according to a cycle and a direction of said 1st diffraction grating.

[Claim 19 The projection exposure method according to claim 5 the refractive index's n having filled between said 1st diffraction grating and said substrates with a larger fluid than 1, and setting NA of said projection optical system as the range of 0.5<NA<n 2.

[Claim 20 In a projection aligner which has a projection optical system of the numerical aperture NA and the reduction percentage M:1 which carry out image formation of the pattern on the above-mentioned mask to an illumination-light study system which irradiates a mask on a mask stage with light of the wavelength lambda which emitted a light source near the substrate face on a substrate stage, It has the 1st diffraction grating of the 1st space cycle P1 (lambda (1.42 and NA) < P1 < lambda NA) parallel to the above-mentioned substrate between the above-mentioned substrate and the above-mentioned projection optical system, So that an image of a mask pattern may be reproduced by interference of light diffracted by the 1st diffraction grating of the above near the substrates face, A projection aligner having a diffraction grating, the 2nd diffraction grating and the 3rd diffraction grating, of two sheets sequentially from the above-mentioned mask side in the above-mentioned mask and parallel between the above-mentioned mask and the above-mentioned illumination-light study system.

[Claim 21 The projection aligner according to claim 20, wherein period directions of the 1st, 2nd, and 3rd diffraction gratings of the above are equal and the space cycle P1 of the 1st diffraction grating of the above, the space cycle P2 of the 2nd diffraction grating, and the space cycle P3 of the 3rd diffraction grating fill relation between about 1 P3 1 (M-P1) 1 P2.

[Claim 22 Each installed position of the 1st diffraction grating of the above, the 2nd diffraction grating of the above, and the 3rd diffraction grating of the above, Thickness of each transparent substrate which provides the 1st diffraction grating of the above, the 2nd diffraction grating of the above, and the 3rd diffraction grating of the above, And the projection aligner according to claim 20 setting up a cycle of the 2nd diffraction grating of the above according to physical relationship of NA of said projection optical system and reducing magnification, and each diffraction grating and the above-mentioned substrate so that aberration between the above-mentioned mask surface and the image surface may serve as the minimum.

[Claim 23 Between said substrate and said 1st diffraction grating, width to said one way by below Z1 and NA. [whether a space cycle has a shielding pattern of 2 and NA-Z1 mostly,

and] Or the projection aligner according to claim 20 having a function which scans and exposes on a substrate an exposure region restricted with the above-mentioned shielding pattern, or is exposed while moving to step form.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention
[0001]
[Industrial Application This invention relates to the pattern formation method for forming the minute pattern of various solid state components, and the projection aligner used for this.
[0002]
[Description of the Prior Art In order to improve the degree of location and working speeds of a solid state component, such as LSI, the minuteness making of the circuit pattern is progressing. Minuteness making of the pattern is desired for the improvement in the characteristic of light and electronic devices and various kinds of quantum effect elements, such as laser, a dielectric, a magnetic body element, etc. The reduced-projection-exposure method excellent in mass production nature and resolution performance is widely used for the pattern formation of these now. Since the resolution limit of this method is proportional to an exposure wavelength and in inverse proportion to the numerical aperture (NA) of a projection lens, improvement in a resolution limit has been performed by short wavelength formation and high NA-ization.
[0003]The various image improving methods, such as a phase shift method, a deformation illumination method (oblique incidence illumination), and a pupil filter method, are applied as a technique for improving the resolution of a reduced-projection-exposure method further. these -- the former -- the performance of an optical system -- until [theoretical] diffraction marginal (interception spatial frequency 2 NA lambda) last-minute -- it will be used effectively. The these image improving method (often called a super resolution method) is discussed by the 49th page (science forum company **, 1994, Tokyo) from innovation of a ULSI lithography technology, Chapter 1, and the 34th page, for example.
[0004]On the other hand, some methods of expanding the spatial frequency band of an optical system are known as a method of improving the resolution of a microscope across the conventional above-mentioned diffraction limit. These spatial frequency band dilation is discussed by the 859th page (1968) from applied physics, the 37th volume, No. 9, and the 853rd page, for example. One of methods of this is what scans two lattice patterns keeping

conjugation relation mutual right above an object and an image (at least inside of the depth of focus), A moire pattern is formed by superposition of an object and the 1st lattice pattern of the right above of it, and it gets over by passing a lens system and piling up this moire pattern with the 2nd lattice pattern by the image side. Since a moire pattern has spatial frequency lower than an object and the 1st lattice pattern, it can pass a lens system. It applies for applying this method to a reduced-projection-exposure method. Generally, since it is difficult, it is operating scanning a lattice pattern mechanically right above wafer as a lattice by providing a photochromic material directly on a wafer and scanning an interference fringe in piles to this.

[0005]

[Problem(s) to be Solved by the Invention however, the above -- there are the following technical problems in various conventional technologies.

[0006]As for the short wavelength formation of exposing light, an ArF excimer laser (wavelength of 193 nm) is first considered to be a limit from the problem of the transmissivity of optical (lens) material. As for NA of a projection optical system, 0.6-0.7 are considered to be limits from a lens design and a manufacturing problem. However, the resolution limit of the exposing method is about 0.3 lambda NA, when 0.5 lambda NA and a cycle type phase shift method are generally used, therefore even if it uses the limit of the above-mentioned short wavelength formation and a raise in NA, formation is conventionally difficult for a pattern of 0.1 micrometer or less. In the above-mentioned cycle type phase shift method, since a mask pattern is restricted, a actual limit size retreats further about a more general circuit pattern. Although expansion of the exposure area is demanded with large-scale-izing of LSI, it is very difficult to satisfy simultaneously expansion of the exposure field of a projection optical system, and the demand of a raise in NA.

[0007]On the other hand, the various spatial frequency band dilation aiming at crossing the conventional diffraction limit aims at expanding a minute object for a microscope. For this reason, there was a problem that it was not necessarily suitable in forming the minute optical image demanded by optical lithography. For example, in the method of using said moire pattern, the mechanism or optical system for scanning two lattices, keeping conjugation relation mutual right above a mask and a wafer becomes it is remarkable and complicated. Since exposure of resist is substantially performed by evanescent light, there are problems, like it becomes difficult for light to decline in a wavelength range and to expose thick resist. Even when using photochromic one, there is no suitable material. Therefore, when mass production of LSI was considered, there was a problem that it could not necessarily be said that it is practical.

[0008]In the projection exposure method which forms the minute pattern of various solid state components, the purpose of this invention is to provide the method of improving the resolution across the conventional diffraction limit (interception spatial frequency). Specifically, it is in providing the new projection exposure method with which an effect almost equivalent to having doubled a maximum of the NA substantially is acquired, and

the exposure device which makes this possible, without changing NA of a projection optical system.

[0009]The thing of a resolution improved effect to acquire is possible for another purpose of this invention only by adding some improvement to these, without changing greatly the composition and the optical system of an exposure device of a conventional type, And it is in providing a projection exposure method suitable for mass production of LSI with which it is simultaneously satisfied of a big exposure field and high resolution.

[0010]

[Means for Solving the Problem When carrying out image formation of the above-mentioned purpose to up to a substrate using light of the wavelength lambda according to a projection optical system (numerical aperture NA, reduction percentage 1:M) of MASUKUPATAN and forming a pattern, between the above-mentioned substrate and the above-mentioned projection optical system, While providing the 1st diffraction grating of the space cycle P1 (however, it is desirable that it is lambda (1.42 and NA) < P1 < lambda/NA) in the above-mentioned substrate and parallel, It is attained by providing a diffraction grating, the 2nd diffraction grating and the 3rd diffraction grating, of two sheets in the above-mentioned mask and parallel sequentially from the above-mentioned mask side between said projection optical system and said mask so that an image of a mask pattern may be reproduced by interference of light diffracted by the 1st diffraction grating of the above near the substrates face.

[0011]In order to reproduce an image of a mask pattern faithfully by the diffracted light of the 1st diffraction grating, Period directions of the 1st, 2nd, and 3rd diffraction gratings of the above are equal, and the space cycle P1 of the 1st diffraction grating of the above, the space cycle P2 of the 2nd diffraction grating, and the space cycle P3 of the 3rd diffraction grating are set up so that a relation of about 1/P 3 1 P2-1/(M-P1) may be filled. The optical distance Z1 from the above-mentioned substrate face of the 1st diffraction grating of the above and the optical distance Z2 from the above-mentioned mask surface of the 2nd and 3rd diffraction grating of the above, and Z3 are set up so that a relation of P2 (Z3-/M+Z1andM) P1 may be filled mostly (Z3-Z2). It is desirable that it is P2< 1 (1-2 and NA/M). It is preferred to set up an installed position of the 1st, 2nd, and 3rd diffraction grating, thickness of a transparent substrate of each diffraction grating, and a cycle of the 2nd diffraction grating so that aberration between the above-mentioned mask surface and the image surface may serve as the minimum. It is preferred that a space cycle provides mostly the 1st shielding pattern of the above and the 2nd shielding pattern that shades an almost conjugate field for the 1st shielding pattern of 2, Z1, and NA right above said mask or in directly under again, and width restricts an exposure region by below Z1 and NA between a substrate and the 1st diffraction grating.It is preferred to scan and expose on a substrate an exposure region restricted above-mentioned] if needed, or to expose, moving to step form. As for these each diffraction grating, it is preferred that it is a phase grating.

[0012]As for said diffraction grating, it is preferred to consider it as a one-dimensional

diffraction grating, and to carry out aberration compensation of the wavefront aberration of said projection optical system so that it may become axial symmetry centering on a diameter of a direction vertical to period directions of the above-mentioned diffraction grating on a pupil. This invention demonstrates a big effect especially, when a cycle type phase shift mask is used as a mask. It is desirable to restrict a cycle and a direction of a detailed pattern according to a cycle and a direction of a diffraction grating, or to amend pattern shape if needed. If the refractive index n fills between the 1st diffraction grating and said substrates with a larger fluid than 1 and NA of said projection optical system is set as the range of 0.5<NA<n 2, formation of a still more detailed pattern will be attained.

[0013]

[Function]In this invention, a diffraction grating is provided between the last element of a projection optical system, and a wafer, and the incidence angle of the optical beam which enters into a wafer surface is enlarged.

Therefore, an effect equivalent to increasing NA effectually will be acquired.

However, only by providing a diffraction grating between the lens wafers of an optical system conventionally simply, the diffracted lights which should originally be collected to one on the image surface are scattered all over the scattering position on the image surface, and reproduction of a mask pattern is difficult absolutely. Therefore, it is necessary to reconstruct an optical system so that an image faithful to the original mask pattern may be reproduced as a result of interference. And as for the viewpoint of practicality to these optical systems, it is preferred that it is moreover usable in the conventional mask, without converting the conventional projection optical system greatly. This invention satisfies these demands so that it may state below.

[0014]In order to explain an operation of this invention, the principle of the image formation by this invention is explained as compared with a conventional method. The situation of the image formation at the time of illuminating a mask or a phase shift mask the case where it illuminates vertically respectively, and aslant, conventionally by the conventional projection exposure optical system is shown in drawing 2 a, b, c, and d for the again comparison with drawing 1 of the image formation in the optical system based on one gestalt of this invention. With any figure, 2:1 reduction optical systems, coherent illumination, and a one-dimensional pattern were assumed, and paraxial image formation approximation was carried out.

[0015]First, when vertical illumination of the mask is usually conventionally carried out by an optical system (drawing 2 a), it diffracts with the pattern on a mask, the beam of light which passed the pupil 24 (inside of the diaphragm 20) of the projection optical system 23 among the diffracted lights converges and interferes on the image surface 25, and the light 22 which carried out vertical incidence to the transmission type mask 21 forms a pattern. Here, if the pattern cycle which gives the greatest angle of diffraction that can pass a pupil is defined as a resolution limit, a resolution limit will become lambda/(2NA) (however, NA=$\sin theta_0$). If the cycle type phase shift mask 26 is applied to this optical system, as

shown in drawing 2 b, the zero-order diffracted light will disappear and the diffracted light will arise symmetrically to the optic axis 29 (dashed dotted line in a figure). For this reason, the greatest angle of diffraction that can pass a pupil will be twice, and a resolution limit improves to lambda (4NA).

[0016]moreover -- centering on a zero order light among the mask diffracted lights, if slanting lighting is conventionally applied to an optical system (the zero order light 27 of the mask diffracted light assumed that it passed through the left end of since it was easy, drawing 2 c and) -- positive negative -- only a single-sided ingredient (a figure primary [+] light 28) with one of angles of diffraction passes a pupil, and converges on the image surface. Since the diffracted light which has a twice in the case of vertical incidence as many angle of diffraction as this can pass a pupil, a resolution limit becomes lambda/(4NA) too. However, in order to use only one side of a diffraction spectrum, the resolution of an isolated pattern is not different from the case of vertical illumination, and there is a problem of contrast falling also in the case of a period pattern, for example. Since two or more diffracted lights cannot pass a pupil if a mask is changed into the cycle type phase shift mask 26, a pattern is not resolved (drawing 2 d).

[0017]Next, the image formation in the optical system based on one gestalt of this invention is shown in drawing 1. In the conventional optical system of drawing 2, the diffraction grating A and the diffraction grating B are inserted between the mask 1 and the projection optical system 2, and the optical system of drawing 1 inserts the diffraction grating C between the projection optical system 2 and the wafer 4 again. Here, let both the diffraction gratings A, B, and C be phase gratings.

[0018]The light R which carried out vertical incidence to the mask 1 is diffracted by the zero-order diffracted light R0, the primary [+] diffracted light R1, and primary [-] diffracted-light R1' in a mask surface. The zero order light R0 reaches the point A0 on the diffraction grating A, it diffracts in the primary [**] direction the point C0 on the diffraction grating C through the left end of the pupil 3 (inside of the diaphragm 5), and the light diffracted in the -primary direction there reaches 2on the image surface Q, and P respectively, after diffracting in the primary [+] direction the point B0 on the diffraction grating B. The primary [+] diffracted light R1 reaches the point A1 on the diffraction grating A, it diffracts in the primary [**] direction the point C1 on the diffraction grating C through the right end of the pupil 3, and the light diffracted in the -primary direction there reaches the points Q and P on the image surface too, after diffracting in the primary [+] direction the point B1 on the diffraction grating B. on the other hand -- a point -- A -- zero -- +-- one -- order -- a direction -- diffracting -- having had -- a zero order light -- R -- zero -- ' -one -- order -- the diffracted light -- R -- one -- ' -- receiving -- an optical path -- **** -- two -- beams of light -- an optical path -- an optic axis -- six (dashed dotted line in a figure) -- receiving -- being symmetrical -- becoming . That is, it diffracts in the primary [**] direction the point C0 on the diffraction grating C eventually, and both reach the point P on the image surface, and Q'. Therefore, the zero order light diffracted with the mask and three beams of light of primary -a

primary beam of light cross at P point. This depend on a mask angle of diffraction is clear. Therefore, at the point P, a diffraction pattern is reproduced faithfully.

[0019]Since the diffracted light with a twice as many angle of diffraction as this can pass a pupil using the optical system which has the same NA and magnification compared with a conventional method (drawing 2 a), the effect same with having doubled NA substantially is acquired. moreover -- centering on a zero order light with slanting lighting (drawing 2 b) -- positive negative -- either, since the diffracted light of both sides is renewable by this invention in the image surface to only diffracted light of one of the two being renewable in the image surface, With slanting lighting, the improvement in resolution of the difficult isolated pattern is possible, and big contrast can be acquired to a period pattern. If a cycle type phase shift mask is applied to this optical system (drawing 3 a), as a result of primary [+] light R+ and primary -light R- which the zero-order diffracted light disappears and have a twice [usual] as many angle of diffraction as this interfering, the degree of minimum solution image becomes lambda/(8NA). This is a half of lambda/(4NA) which is a theoretical limit at the time of using a cycle type phase shift mask and slanting lighting until now. Improvement in fast resolution is attained by this invention.

The situation of the image formation at the time of applying slanting lighting in this optical system is shown in drawing 3 b. With slanting lighting, it becomes possible to pass a pupil to diffracted-light R1" which has a big angle of diffraction only to one side, and resolution can be improved to the twice a maximum of (8NA), i.e., lambda , at the time of vertical illumination. If various illumination light from which a mask incidence angle differs is used, the effect of partial coherent lighting can be acquired completely in a similar manner in an optical system conventionally.

[0020]It is as follows when the principle of this invention is explained from the position of the Fourier diffraction theory (drawing 4). In the following explanation, the magnification of an optical system shall consider 1 and a diffraction grating shall consider only the primary [**] diffracted light by a one-dimensional phase grating. From the point P on the image surface, when the pupil 3 is seen via the diffraction grating C, a pupil divides and is visible to two by diffraction (drawing 4 a). In each pupil, the mask Fourier transform image which passes a pupil at the specific angle which exists respectively is in sight. On the other hand, considering the mask side, it diffracts by the diffraction gratings A and B, and the light diffracted with the mask forms two or more mask Fourier transform images on a pupil. Among these, what passed the pupil at a certain specific angle can be seen in the pupil which was visible in the top (drawing 4 b). That is, in the case of drawing 4, the Fourier diffraction pattern on the right of drawing 4 b appears in the pupil on the left-hand side of drawing 4 a, and the Fourier diffraction pattern on the left of drawing 4 b appears in the pupil on the right-hand side of drawing 4 a. At this time, conditions for an image to be correctly reproduced at the point P are the following two points.

[0021](1) The spectrum of the same point on a mask should be in sight via two pupils.

[0022](2) Two spectra should connect continuously at the point of contact of two pupils.

[0023]It is necessary to enable it in other words to see one continuous spectrum via two or more pupils.

[0024]seeing from an image and passing the diffraction grating C -- f' -- two or more shifted pupils being able to be seen, and passing the diffraction gratings B and A in each of that pupil -- too -- f'' -- supposing two or more shifted Fourier diffraction patterns appear, amplitude distribution u(x) of a true image is expressed with a following formula.

[0025]

u(x) -- =F [sigmap(f-f') -sigmao (f-f'')] -- f' SCf (SA-SB-SC) -- here, F[] expresses the sum to the order of diffraction with which the Fourier transform and p (f) differ between a pupil function and o (f), a mask Fourier diffraction pattern and x differ between real space coordinates and f, and spatial frequency coordinates, SA, SB, and SC differ between sin (sine) of the angle of diffraction of the diffraction grating A, B, and C, and sigma. Therefore, if SA=SB SC, the paragraph which is set to f 0 and set as opposed to both both f' SC(s) to f 0 can be acquired. That is, the one spectrum o (f) can be seen via the two pupils p (f**SC). what is necessary is just to make the distance between a mask surface and the diffraction gratings A and B and the distance between the diffraction grating C and the ideal image surface, each ZA, ZB, and ZC into SA-(ZB-ZA) SC- (ZB ZC), in order to acquire the image over a same-on mask point at the point P

[0026]When the upper conditions are applied to the optical system of the reduction percentage M:1 and the image side numerical aperture NA under paraxial approximation, it turns out that what is necessary is just to set up the distance ZC between the cycles PA, PB, and PC of the diffraction grating A, B, and C, a mask surface, and the distance ZA between the diffraction gratings A and B, ZB and the diffraction grating C and the ideal image surface almost as follows.

[0027]In order to acquire sufficient resolution improved effect by this invention to a 1/PA 1 PB-1/(M-PC) (ZB-ZA) PA (ZB M M-ZC)/PC pan, it is preferred to consider it as lambda/NA< PC < root2 and lambda/NA.

[0028]As for the diffraction gratings A and B, it is preferred that it is a phase grating. When the diffraction gratings A and B penetrate not a perfect phase grating but a zero order light, effects, such as an optical system and an oblique incidence optical system, lap with the effect of this method conventionally which is inferior to definition from this method. For this reason, there is a possibility that definition may deteriorate. On the other hand, even if the diffraction grating C is a phase modulation lattice and it is an amplitude strength phase modulation grating, it is not cared about. The cycle of the diffraction grating C is quite small, and considering the silicon oxide of the refractive index 1.5, the section aspect ratio of a lattice pattern becomes about about one. In this case, it needs to be cautious of the scattering effect of the light in a pattern section. In the case of the diffraction grating which consists of shielding patterns, since thickness of a light-shielding film is made quite thinly, the influence of dispersion can be reduced. However, the direction which uses a phase modulation lattice can make an exposure region large so that it may state later.

[0029]If the refractive index n fills the substrate side of the diffraction grating B with a larger fluid than 1 etc., the wavelength of this field and sin of an angle of diffraction will turn into 1/n. Then, the cycle of the diffraction grating B is further made fine, and if an angle of diffraction is made equal to the case where a fluid is not filled, since only wavelength is set to 1/n, resolution will also improve to 1 n. In the mask side, it is necessary to increase a mask lighting angle but so that the diffracted light with a bigger angle of diffraction can pass a pupil, and it becomes impossible in this case, for the diffracted light with a small angle of diffraction to pass a pupil at this time. Then, it is desirable to increase the path of a pupil according to this. This can also be put in another way as follows. When the refractive index between the diffraction grating B and a substrate is 1, the improvement in resolution is not obtained at all as for 0.5 or more in NA of a projection optical system used by this invention. It is for the angle of diffraction over the beam of light which enters into the diffraction grating B of periodic lambda NA at an angle of theta sintheta>0.5 being 90 degrees or more, localizing it on the diffraction grating surface as an evanescent wave, and not getting across to a wafer. On the other hand, if the refractive index between the diffraction grating B and a substrate is set to n, Angle-of-diffraction theta' of the light which entered into the diffraction grating B (it must be periodic lambda NA in order for the zero order light which passed the end of the pupil to carry out vertical incidence to a wafer) at an angle of sin theta=NA becomes sintheta' (lambda PB sintheta) n 2 NA n, and the conditions for being theta'<90 degree, It is set to NA<n 2. That is, this invention is effectively applicable to the optical system of maximum NA n 2. Although a dipping optical system generally needs a special optical design, when it applies to this invention as mentioned above, a special lens is not needed at all. Therefore, if between the diffraction grating B and substrates is filled with water (refractive index 1.3 about) and is exposed using an about 0.6 NA by which normal use is carried out in the semiconductor process] projection lens, an effect equivalent to having set NA to 1.2 substantially will be acquired. In this case, if a phase shift mask is used, the resolution of 0.1 micrometer or less will be obtained also on the wavelength (365 nm) of i line of a mercury lamp. In this method, since the incidence angle of light in which it interferes near the wafer is very large, it depends for image formation performance to the polarization condition of light strongly. It is desirable when the direction of the light which has a polarization condition with an electric field vector vertical to the entrance plane of light generally forms the image of high contrast.
[0030]All the above arguments need to assume paraxial approximation, need to set the refractive index of the substrate of a diffraction grating to 1, and need to take into consideration strictly actually the effect of the refractive index of the substrate of a diffraction grating, and the influence of the aberration produced by a diffraction grating. For this reason, the installed position of each diffraction grating may be changed a little. It cannot be overemphasized that it is preferred to make it in agreement in sufficient accuracy as for the period directions of the pattern of two or more diffraction gratings.
[0031]Next, four points are described about the point which it should be careful of in this

invention.

[0032]Generally an exposure region is conventionally restricted to the 1st compared with the exposing method by this optical system. Two beams of light cross also in the point Q on the image surface, and Q', it interferes mutually, and an image is formed so that drawing 1 may show. This image is an image of the imitation produced in the position which should be formed essentially, and which does not come out.

Generally it is not desirable.

In order to avoid this, it is desirable to form the light shielding mask 52 right above the image surface 51 (between a wafer and the diffraction gratings C), and to intercept the image of these imitations, as shown in drawing 5 a. The diffraction grating C and the light shielding mask 52 can be formed in both sides of the same quartz substrate 53 as shown in the figure. (You may form on a separate substrate.) providing again the masking blade which shades this, simultaneously the above-mentioned light shielding mask and an almost conjugate field right above a mask or in directly under in a similar manner -- a mask illuminated field -- the above -- restricting to a conjugate field is preferred. The exposure region which can be transferred by one exposure is a field equivalent to the distance (about 2 and NA-ZB) between a true image (P point) and a fake image (Q point), repeats the twice of the above-mentioned distance as a cycle, and appears. Therefore, when narrower than the area which wants to expose the field which can be exposed, as shown in drawing 5 b, it is desirable to scan an exposure region on a wafer. Under the present circumstances, if the reduction percentage of an optical system is M:1, it cannot be overemphasized that it is desirable to also set strictly the ratio of mask scanning speed to wafer scanning speed to M:1. About the method of carrying out the synchronous scan of these exposure regions on a mask and a wafer, the method used with the existing exposure device can be used as it is. On the other hand, when larger than the area which wants to expose an exposure feasible region (i.e., when the chip whose distance between a true image and a fake image is one piece is covered), it can expose, without scanning. The size of an exposure region is decided by the installed position of the diffraction grating B, and the width of one exposure region increases, so that the diffraction grating B is separated from the image surface. However, since the width of the field which cannot be transferred also increases simultaneously, both rate does not change as [about 1:1]. As for the width W of a wafer top exposure region, in order to eliminate the influence of a fake image, it is desirable to consider it as W< NA-ZB. When an amplitude strength phase modulation grating is used for the diffraction grating B, in order that the zero-order diffracted light of a lattice may form the image of another imitation at the halfway point of a true image and a fake image, when an exposure region is a phase grating, it becomes half mostly.

[0033]Generally by this method, exposure intensity falls to the 2nd. Only the light of the specific order of diffraction is used for the beam of light which carries out image formation on a wafer by this method among the beams of light diffracted by the diffraction grating inserted into the optical system. Therefore, the light intensity which contributes to exposure

whenever it passes a diffraction grating will fall. Having restricted the exposure region on a mask and a wafer, as stated in the top also causes a throughput fall. For this reason, it is desirable to cope with it using resist materials using a light source with sufficiently strong intensity, such as chemical amplification system resist with high sensitivity, etc. by this method.

[0034]As pre- explanation showed 3rd , in addition to the desirable diffraction pattern of f''=0, on a pupil, the Fourier transform image which shifted only f''=**2 (SA+SB) arises. The high order spectrum of a mask pattern means lapping with a low spatial frequency domain substantially, and, generally this does not have it. preferred In order to avoid this in the optical system of drawing 1, it is PA< 1 (1-2 and NA/M).

Then, it is good. In this case, it is because the diffracted light (equivalent to the dotted line emitted out of [A1] drawing 1) of the primary [+] direction by the diffraction grating A to the diffracted light (inside R1 of drawing 1) diffracted by angle-of-diffraction 2 and NA/M with the mask cannot exist.

[0035]By the optical system of this invention, it needs to be 4th cautious of the aberration accompanying diffraction grating introduction. The aberration generated by a diffraction grating is explained using drawing 6. The beam of light after mask passage assumes that it is in a field including the period directions of an optic axis and a diffraction grating (for example, a one-dimensional pattern and coherent illumination). In order for the optical system of drawing 6 a to be non-aberration, the difference of each light path length of $OX_1X_2X_3I$, $OY_1Y_2Y_3I$, and $OZ_1Z_2Z_3I$ must be 0, for example. However, if optical path length difference is among these, this will serve as aberration. When it assumes that a projection optical system is an ideal optical system of the aberration 0 here, from $X_2X_3=Y_2Y_3=Z_2Z_3$. The difference of $OX_1X_2+X_3I$, $OY_1Y_2+Y_3I$, and $OZ_1Z_2+Z_3I$ turns into aberration. If the wavefront aberration of the optical path which results in $OZ_1Z_2Z_3I$ from $OX_1X_2X_3I$ which crosses the diameter of a pupil is plotted to the pupil radius coordinates s standardized on the basis of $OY_1Y_2Y_3I$, it will become like the solid line of drawing 6 b. It turns out that aberration w+ (s) to the beam of light which has an angle of + to a mask passage crepuscular-rays axis generally becomes unsymmetrical on a pupil. Aberration w- (s) to the beam of light which has an angle of - to an optic axis similarly becomes symmetrical as a center from the symmetry of an optical system about w+ (s) and a pupil. In this invention, since it is necessary to make the light diffracted in the direction of , and the light diffracted in the direction of - interfere on a wafer simultaneously, it is necessary to amend the aberration to both simultaneously. However, since the pupil top aberration over the light diffracted in the direction of + and the direction of - is not in agreement so that drawing 6 b may show, it becomes difficult theoretically to amend these by a projection optical system simultaneously. Therefore, as for such aberration, it is preferred to amend between a mask and a projection optical system or between a wafer and a substrate.

Generally this can be performed by the following methods.

[0036]If w (s) and w-(s) is equal, it is possible to amend this by a projection optical system. then -- delta -- w -- (-- s --) -- = -- {-- w -- + -- (-- s --) --} - {-- w - (-- s --) --} -- a pupil -- a top (drawing 6 the range of -1< s< 1) -- wavelength -- comparing -- enough -- it is small -- quantity -- delta -- stopping -- ****ing . On the other hand, deltaw (s) is expressed as a function of the parameters xi (i 1, 2, --), such as relative position relation of the installed position of each diffraction grating, the thickness of the substrate supporting a cycle and a diffraction grating, a refractive index and a substrate, and a diffraction grating. Then, the range of the problem is -1 < s< 1 and it results in calculating xi which fills deltaw(s, xi) <delta. An example describes the example of actual optimization. Anyway, thus, if aberration over the beam of light which has an angle of to a mask passage crepuscular-rays axis is made into a symmetrical form on a pupil, this can be amended in a projection optical system. It is more desirable if the aberration itself can fully be controlled by the method described in the top.

[0037]As mentioned above, since it was easy, the one-dimensional pattern was assumed as a mask pattern, but when a two-dimensional pattern exists actually or partial coherent lighting is used, the beam of light after mask passage is not settled in a field including the period directions of an optic axis and a diffraction grating, but tends toward various points on a pupil. In this case, what is necessary is to consider function deltaw(s, t) {w (s, t)}-{w-(s, t)} of the two-dimensional coordinates (s, t) on a pupil, and just to calculate as deltaw, xi which fills deltaw(s, t, xi) <delta in a pupil surface. This means making w (s, t) into the most symmetrical possible form to s= 0 on a pupil.

[0038]In order to acquire the effect of this invention to all the directions, it is possible to use each diffraction grating as a two-dimensional diffraction grating, as shown, for example in drawing 7 a and b. In this case, the form of the pupil on appearance becomes symmetrical with 4 times. However, except for the case where NA of an optical system is small, it is slightly difficult to carry out aberration compensation simultaneously on a pupil to 2 sets of vertical pupils according to the situation described in the top mutually. For this reason, it is slightly difficult to acquire the effect of this invention equally to all the directions on a mask, and it is more realistic to use a one-dimensional diffraction grating like drawing 8. Drawing 8 a, b, and c see with three typical diffraction gratings, and are the upper pupil shape. In drawing 8 a, substantial NA increases about twice to the pattern of a x direction, but it decreases to the pattern of a y direction. In drawing 8 b, to the pattern of a x direction, substantial NA will be root2 twice and is set to 1/root2 to the pattern of a y direction. As for NA, in drawing 8 c, x and y both directions will be root2 twice, but it is thought that it depends for image formation performance [/ in addition to x and a y direction in the direction of a pattern remarkably. It is desirable to impose restriction by a direction on a mask at the layout rule of a pattern, etc. in any case.

[0039]In order to abolish the pattern direction dependency of image formation performance, the conditions of drawing 8 a, b, and c may be rotated 90 degrees respectively, and

multiple exposure may be performed. When this is especially applied to drawing 8 c, an image equivalent to root y both directions having doubled NA, without x controlling pattern direction dependency [/ in addition to x and a y direction , and sacrificing image contrast can be acquired. However, when rotating a diffraction grating 90 degrees, aberration characteristics also rotate 90 degrees. Then, it is desirable to cope with to perform aberration compensation using a pupil filter and to rotate this 90 degrees with a diffraction grating etc. When aberration control is difficult, a slit filter may be provided in a pupil if needed.

[0040]As shown in drawing 3, when perfect coherent illumination of the cycle type phase shift mask is carried out, the optical path of primary light in which it interferes near the wafer is always symmetrical to an optic axis, and each light path length is equal. Therefore, even if aberration compensation of the optical system is not carried out, minute pattern formation is possible. That is, when using a cycle type phase shift mask under perfect coherent illumination, it is usable, and a two-dimensional diffraction grating as shown in drawing 7 does not depend in the direction of a pattern, but can demonstrate the effect of a phase shift mask to the maximum extent. What is necessary is to expose only a detailed period pattern with a described method, and just to expose other portions by the exposing method conventionally after that, in transferring the mask pattern in which various patterns are intermingled.

[0041]Generally the above-mentioned aberration increases rapidly with the value of NA. For this reason, in an about 0.1 to 0.2-NA optical system, it does not become a problem comparatively. Therefore, when applying to an exposure device for large areas, a reflection type soft-X-ray reduced-projection-exposure device, etc. of low NA and low magnification, various restrictions which were described in the top are reduced.

[0042]As mentioned above, it can be said that this invention is what passes a pupil for the right-and-left-pieces side of the Fourier diffraction pattern centering on a zero-order diffracted-light line independently respectively, and compounds this by the image side. It is already applied to the optical microscope as this view itself is discussed by the above-mentioned literature, but the composition of the optical system realizable on a reduction projection optical system was not devised in this until now. This invention is exactly what realized this skillfully in the reduced-projection-exposure system. That is, the optical system of drawing 1 provides a diffraction grating between a projection optical system and a wafer, and it constitutes an optical system so that an image faithful to the original mask pattern may be reproduced as a result of wafer surface interference, while it enlarges the incidence angle of the optical beam which enters into a wafer surface. This invention is applicable to various projection optical systems, such as a dioptric system, catoptric systems and these combination, a reduction optical system, and an actual size optical system. Also as an exposure method in the case of exposing a mask pattern to up to a wafer using these optical systems, it is applicable to both package transfer a scanning method step-and-repeat one a step and scan, etc. This invention is purely based on the geometric optics

effect so that more clearly than the above explanation. Therefore, the problem resulting from evanescent light use as in the method of using the above-mentioned moire pattern] is not produced. Since it can detach from a wafer, it can install and there are moreover also no necessities, such as a synchronous scan, a diffraction grating is easily realizable far.

[0043]

[Example

(Example 1) Based on this invention, as the scanned type KrF excimer laser projection aligner of NA=0.45, the light source wavelength of lambda 248 nm, and the reduction percentage 4:1 was typically shown in drawing 9, it converted. That is, the transparent quartz plate 103 which has a phase grating pattern was inserted in both sides between the mask 101 and the projection optical system 102 which were installed on the mask stage 100. Between the wafer 105 and the projection optical system 102 which were installed on the wafer stage (sample table) 104, the shielding pattern and the transparent quartz plate 106 which already has a phase grating pattern on one side were inserted in one side so that the shielding pattern side might meet a wafer. The shielding pattern was used as the Cr pattern 1 mm in a cycle of 300 micrometers in width, and the phase grating pattern was used as the Si-oxide-film pattern of cycle = lambda/NA. It is the cycle of the phase grating pattern on the mask side transparent quartz plate 103 of this 4 times by the side of a wafer. Si-oxide-film thickness was set up so that the phase of the light which penetrated the film's existence part and the portion not existing might shift 180 degrees. These patterns were formed like the so-called production processes of a chromium loess phase shift mask using EB lithography. The transparent quartz plate 108 which has 1.2 mm in width and a cycle =4mm shielding pattern was formed in the illumination-light study system 107 side of a mask. The shielding region of the above-mentioned shielding pattern was set up become a shielding pattern on the wafer side transparent quartz plate 106, and conjugate.

[0044]The cycle of the phase grating of transparent quartz plate 103 both sides, thickness, an installed position of each transparent quartz plate, etc. were optimized using the optimization facility of a ray trace program so that the aberration on the projection optical system pupil in the meaning stated to the paragraph of the operation might serve as axial symmetry. The aberration compensation filter 109 was inserted in the pupil posion of a projection optical system for aberration compensation symmetrical with the above-mentioned axis. Here, the aberration compensation filter 109 amends the astigmatism of a direction mainly vertical to the period directions of the above-mentioned diffraction grating. Each of transparent quartz plates which have these diffraction gratings, and aberration compensation filters is exchangeable, and it enabled it to set them as a position promptly. In order to position a transparent quartz plate correctly, the electrode holder (not shown) of each quartz substrate has a slight movement mechanism (not shown), can measure the position of each quartz substrate, and can set it as the position of a request of this. By monitoring an image by the autofocus monitor (not shown) formed on the wafer stage 104, it also made it possible to feed back a monitored result and to adjust the position of each

quartz substrate so that the optimal imaging characteristic might be acquired on the image surface. Aberration compensation may be beforehand performed for the projection optical system itself to the above-mentioned diffraction grating, and an aberration compensation filter is unnecessary in this case. Exposure was performed carrying out the synchronous scan of a mask and the wafer. The stage control system 110 carries out the synchronous scan of the mask stage 100 and the wafer stage 104 with the velocity ratio of 4:1 respectively.

[0045]The mask which has a pattern of various sizes containing a cycle type phase shift pattern was transferred to up to the chemical amplification system positive resist using the above-mentioned exposure device. As a result of performing an after-exposure predetermined development and observing with a scanning type electron beam microscope, the resist pattern with a size of 90 nm (cycle of 180 nm) has been formed with the cycle type phase shift mask to the period directions (x direction) of the above-mentioned phase grating. On the other hand, the resolution of the direction (y direction) vertical to the above-mentioned direction was size a grade of 140 nm (cycle of 280 nm) using the phase shift mask. Then, next, when the phase grating of the three above-mentioned sheets and the aberration compensation filter were rotated 90 degrees, the same mask was exposed and the resist pattern was formed, the resolution to a x direction and a y direction was reversed.

[0046]Although the upper example is limited extremely a cycle, an installed position, etc. of the kind of the kind of optical system, NA, light source wavelength, reduction percentage, resist, and mask pattern, a size and a diffraction grating, and a shielding pattern, these various conditions can be variously changed within limits which are not contrary to the main point of this invention.

[0047]The example which optimized the optical system is shown so that the influence of (Example 2), next the aberration accompanying diffraction grating introduction may serve as the minimum. In the optical system of drawing 10, the mask surface of a projection optical system and the image surface where mask surface of an optical system and the image surface, sigma, and sigma' does not introduce a diffraction grating, and hi (i 1-6) show the distance in a figure. [where O and I introduced the diffraction grating The shielding pattern of the diffraction grating A, B, and C and wafer right above was formed in both sides of a transparent quartz substrate like Example 1. At this time, transverse aberration w** (s) to the beam of light which has an angle of ** to an optic axis after mask passage is expressed as follows as a function of the standardization pupil radius coordinates s.

[0048]

w**(s) =wu**(s)+ws** (s). wu**. (s) $=C_1h_1+C_2$. (s_1) h_2 -- $+C_5h_5+C_6h_6$ws**(s) =C -- $_3h_3+C_4h_4C_1$=tan[(second**s_0) /M] / M. C_2=tan [**(s_1/n)-(second**s_0)/(nM)] /M, C_3=tan [s/M]/M, C_4=(s) and tan, and C_5=tan[(second**s_0) /n] C_6=tan (second**s_0) -- here, wu

expresses an unsymmetrical ingredient and an ingredient with symmetrical ws to s 0 on a pupil. However, they are s_0=NA and s_1= lambda/PA. When s_0 (NA), the reducing magnification M, and the refractive index n of a transparent quartz substrate are made into a value peculiar to a system, an upper type contains seven optimizing parameters, hi (i 1-6), and s_1. Then, these values were optimized wu and by imposing seven constraints that aberration should be made the minimum to ws** (s) (s). An example of an optimization result to some NA(s) is shown in Table 1. However, aberration was expressed with the wavefront aberration which makes h_5/lambda a unit.

[0049]
[Table 1]

表 1

NA	0.1	0.2	0.3	0.4
h_1/h_5	17.352	16.167	14.263	11.343
h_2/h_5	0.529	0.995	1.343	1.507
h_3/h_5	24.014	22.800	20.137	14.819
h_4/h_5	0.368	0.485	0.652	0.920
h_6/h_5	0.01	0.01	0.01	0.01
s_1	1.225	1.259	1.300	1.349
$w_{max}(s)$	$5x10^{-9}$	$3x10^{-7}$	$4x10^{-6}$	$5x10^{-6}$
$w^u_{max}(s)$	$1x10^{-12}$	$1x10^{-9}$	$2x10^{-7}$	$1x10^{-5}$

$w^u_{max}(s) = \max[w+(s) - w-(s)]$

$s1 = n\lambda/PA$

[0050]As shown in a table, it was possible to fully have suppressed aberration also in NA=0.4. The same optimization can be performed to various arrangement, when the diffraction gratings A and B are respectively formed on another transparent substrate. Still severer aberration conditions can be satisfied by increasing the parameter of optimization by introducing a new transparent substrate and diffraction grating.

[0051]The example which created DRAM of a 0.1-micrometer design rule is described using the exposure device shown in (Example 3), next Example 1. Drawing 11 shows the making process of the above-mentioned device focusing on an exposure process.

[0052]First, the isolation 202 and the gate 203 were formed on Si substrate 201 in which the well (not shown) etc. were formed (drawing 11 a). The isolation and the gate pattern were exposed with the exposure device shown in Example 1 using the cycle type phase shift mask. Here, since it was predicted that the portion into which pattern shape is distorted in the periphery of a period pattern with a simulation arises, the mask for removing this garbage was prepared. After piling up and exposing the above-mentioned mask using an exposure device to the same resist film as what performed the above-mentioned exposure

conventionally, negatives were developed, and the portion which is not preferred was removed on circuit performance. It may be coped with by ignoring in circuit, without removing the above-mentioned garbage.

[0053]Next, the capacitor 204 and the contact hole 205 were formed (drawing 11 b). The electron beam direct writing method was used for pattern exposure of a contact hole. Next, the 1st layer wiring 206, a through hole (not shown), and the 2nd layer wiring 207 were formed (drawing 11 c). The 1st layer wiring (0.1micromL/S) was exposed using the exposure device shown in the cycle type phase shift mask and Example 1. However, the direction and size of each diffraction grating were changed into what was shown in drawing 9 c here, this was rotated further 90 degrees, and multiple exposure was performed. At this time, the aberration compensation filter 109 was also simultaneously rotated 90 degrees with the diffraction grating. 0.1micromL/S has been formed without direction dependency to the wiring prolonged in both directions in every direction by this. Formation of the through hole used the electron beam direct writing method like the contact hole. Subsequent multilevel interconnection patterns and final passivation patterns are designed with a 0.2-micrometer rule, and were formed by the usual KrF excimer laser projection exposure method do not use this invention. It is not caught by what was used in the above-mentioned example about the structure of a device, material, etc., but can change.

[0054]The example which applied this invention to manufacture of distributed feedback type (DFB) laser is described as (Example 4), next another example of this invention. What converted the ArF excimer laser reduced-projection-exposure device of NA0.5 like Example 1 was used for the exposure device. In the making process of the conventional 1 4 wavelength-shift DFB laser, the diffraction grating with a cycle of 140 nm currently formed using the electron-beam-lithography method etc. was formed using the cycle type phase shift mask and the above-mentioned exposure device. It became possible to manufacture more the DFB laser which has by this performance almost equivalent to what was produced using the electron-beam-lithography method etc. for a short period of time.

[0055]

[Effect of the Invention As mentioned above, when irradiating a mask via an illumination-light study system, carrying out image formation of the mask pattern to up to a substrate according to a projection optical system in this invention and forming a pattern, while providing a diffraction grating in the above-mentioned substrate and parallel between the above-mentioned substrate and the above-mentioned projection optical system, A diffraction grating or an image formation optical system is established between a projection optical system and a mask or between a mask and an illumination-light study system so that the image of a mask pattern may be reproduced by interference of the light diffracted by the above-mentioned diffraction grating near the substrates face.

Therefore, formation of the minute pattern conventionally beyond the resolution limit of the exposure device is attained.

Specifically, an effect almost equivalent to having doubled a maximum of the NA

substantially is acquired, without changing NA of a projection optical system. Without changing the fundamental composition of the optical system of an exposure device greatly thereby conventionally, a big exposure field and high resolution are acquired and manufacture of LSI of size the class of 0.1 micrometer is attained using reduction projected light lithography suitable for mass production.

[0056]

[Translation done.]

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DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings
[Drawing 1 It is a mimetic diagram showing geometrically the principle of the image formation of one optical system by this invention.
[Drawing 2 It is a mimetic diagram showing the principle of the image formation by the exposing method conventionally various .
[Drawing 3 It is a mimetic diagram showing the principle of the image formation at the time of applying a phase shift mask or slanting illumination to one optical system by this invention.
[Drawing 4 It is a mimetic diagram showing the principle of the image formation of one optical system by this invention in diffracted-light study.
[Drawing 5 It is a mimetic diagram showing a part of one optical system and an example of an exposure method by this invention.
[Drawing 6 It is a mimetic diagram showing the characteristic of one optical system by this invention.
[Drawing 7 It is a mimetic diagram showing the optic used by this invention, and the effect acquired by that cause.
[Drawing 8 It is a mimetic diagram showing the optic used by this invention, and the effect acquired by that cause.
[Drawing 9 It is a mimetic diagram showing the composition of the exposure device by one example of this invention.
[Drawing 10 It is a figure showing the characteristic of another example of this invention.
[Drawing 11 It is a mimetic diagram showing the device manufacturing processes by another example of this invention.
[Description of Notations
1 [-- A wafer, 5, 20 / -- It extracts, -- A mask, 2 -- A projection optical system, 3 -- A pupil, 4 6, 29 [-- Zero-order diffracted light,] -- An optic axis, A, B, C -- A diffraction grating, R -- Light, R0, R0' R1, R , R1 -- The primary [+] diffracted light, R1', R --- -primary diffracted light, A0, A1 -- The point on the diffraction grating A, B0, B1 -- The point on the diffraction

grating B, C0, C1, C1' -- The point on the diffraction grating C, Q, P, Q' -- Projection optical system,] -- The point on the image surface, 21 -- The conventional transmission type mask, 22 -- Light, 23 24 [-- The zero order light of the mask diffracted light, -- A pupil, 25 -- The image surface, 26 -- A cycle type phase shift mask, 27 28--primary [+] light, 51 -- The image surface, 52 -- A light shielding mask, 53 -- Quartz substrate, O -- The point on a mask, X_1, Y_1, Z_1 -- The point on the diffraction grating A, X_2, Y_2, Z_2 -- The point on the diffraction grating B, X_3, Y_3, Z_3 -- The point on the diffraction grating C, I -- The point on the image surface, 100 [-- Transparent quartz plate, -- A mask stage, 101 -- A mask, 102 -- A projection optical system, 103 104 -- An illumination-light study system, 108 / -- A transparent quartz plate, 109 -- An aberration compensation filter, 110 / -- A stage control system, 201 / -- Si substrate,] -- A wafer stage (sample table), 105 -- A wafer, 106 -- A transparent quartz plate, 107 202 -- A contact hole, 206 / -- The 1st layer wiring, 207 / -- The 2nd layer wiring.] -- An isolation, 203 -- A gate, 204 -- A capacitor, 205

[Translation done.]

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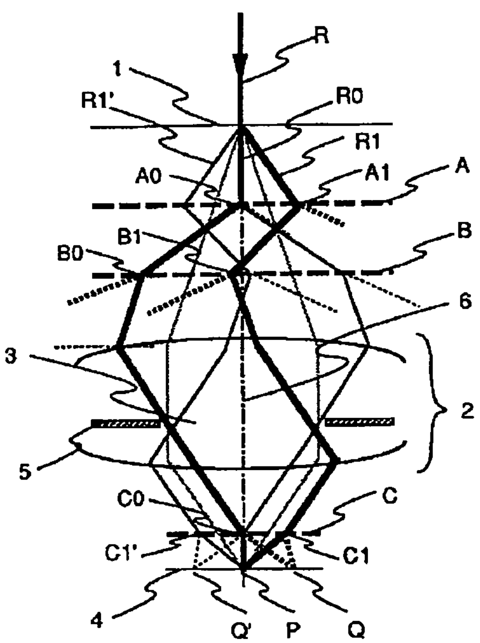
DRAWINGS

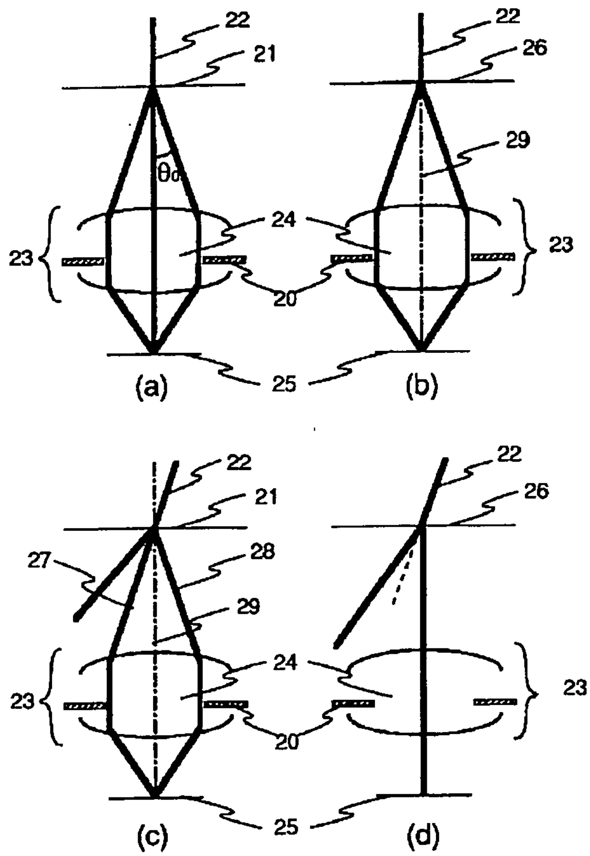
[Drawing 1

図1



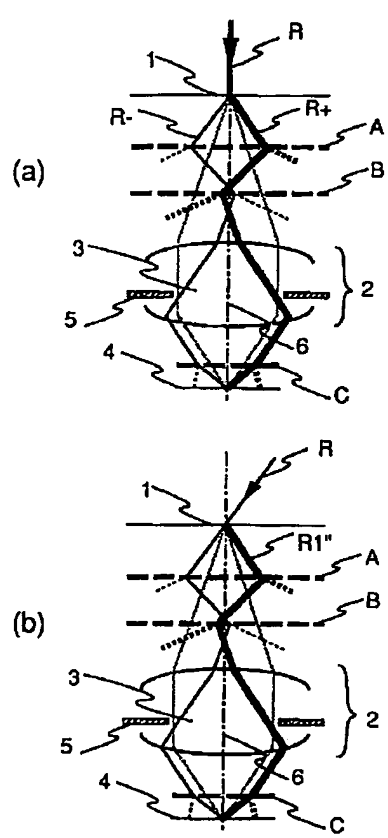
[Drawing 2

図2



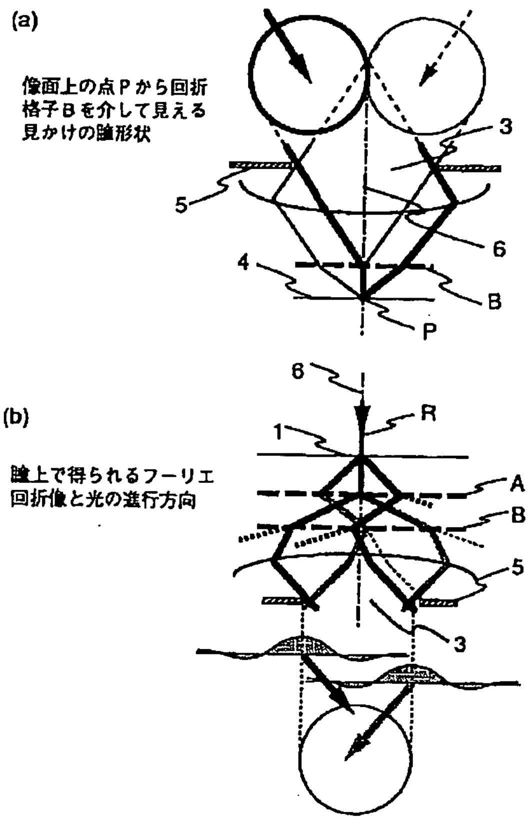
[Drawing 3

図3



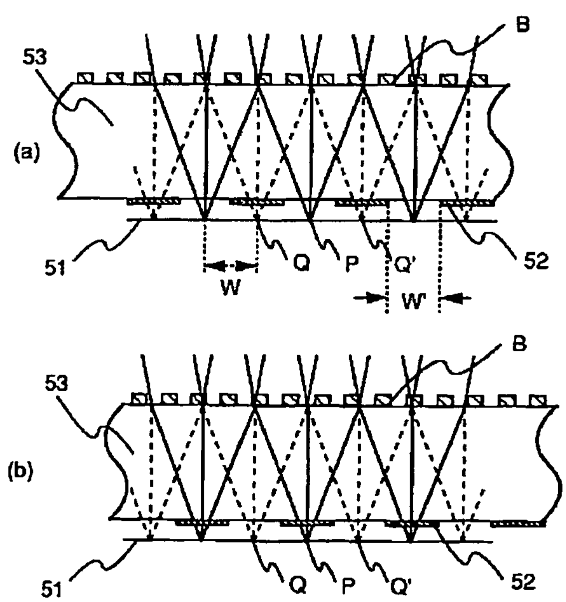
[Drawing 4

図4



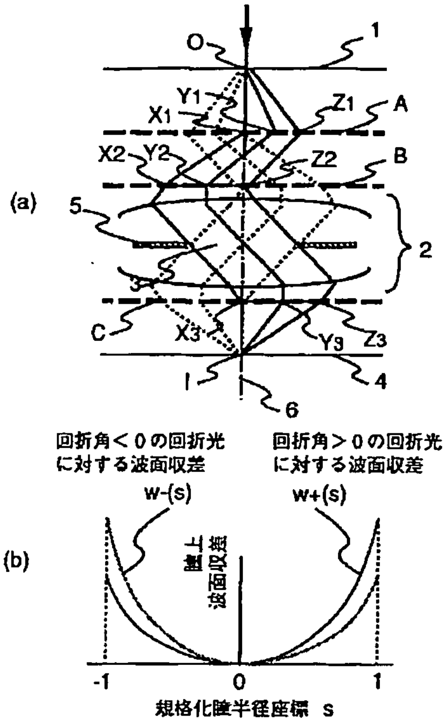
[Drawing 5

図5



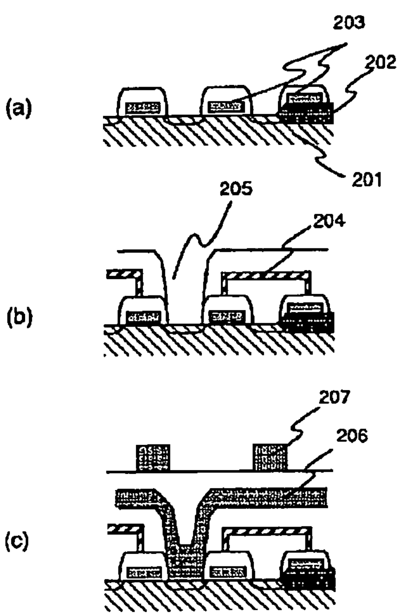
[Drawing 6

図 6



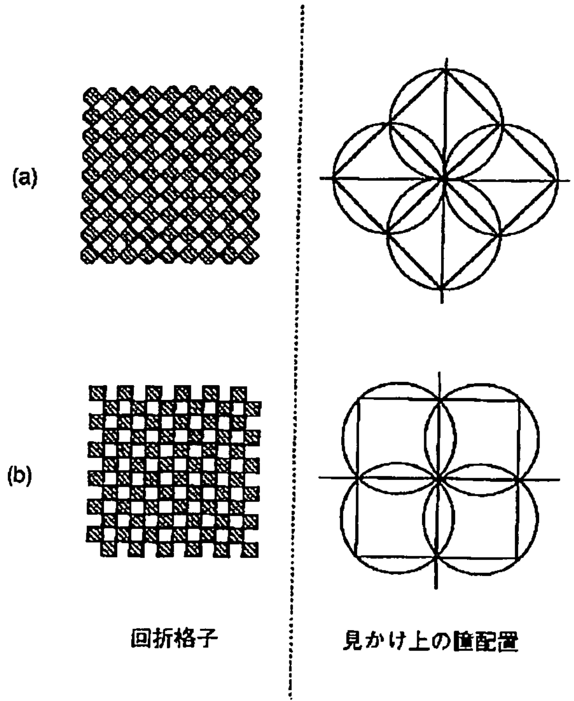
[Drawing 11

図１１



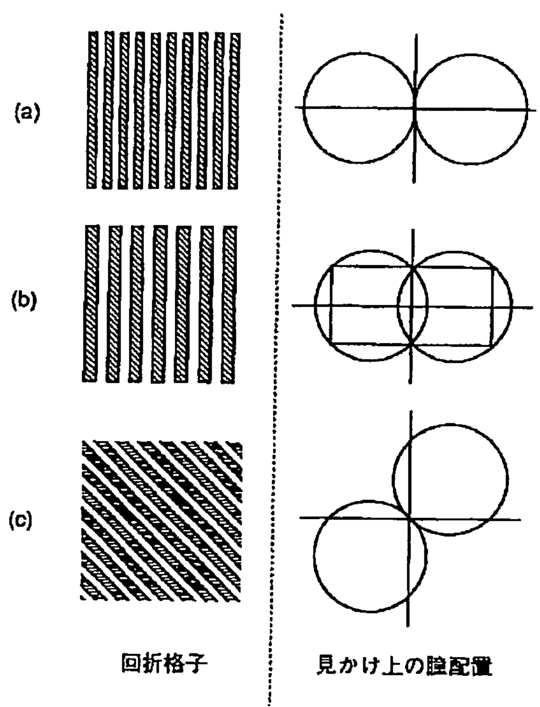
[Drawing 7

図7



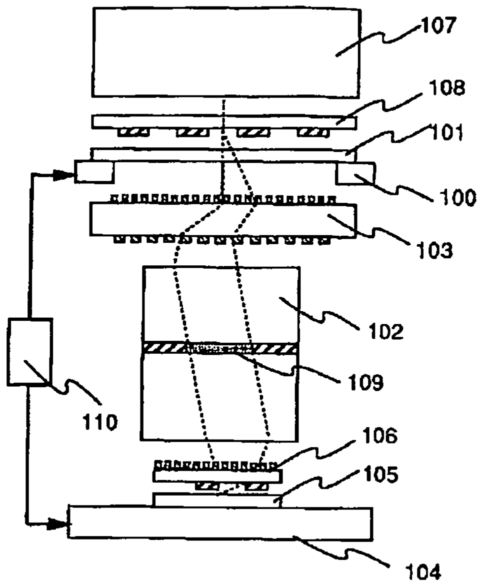
[Drawing 8

図8



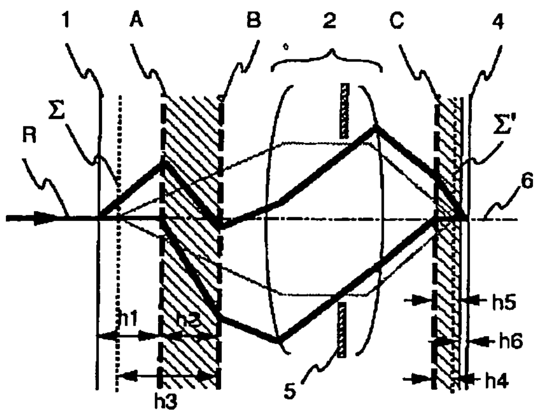
[Drawing 9

図9



[Drawing 10

図1 0



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(19)日本国特許庁（ＪＰ）　(12) 公開特許公報（Ａ）　(11)特許出願公開番号

特開平8－316125

(43)公開日　平成８年(1996)11月29日

(51)Int.Cl.^{6}	識別記号	庁内整理番号	ＦＩ	技術表示箇所
Ｈ０１Ｌ　21/027			Ｈ０１Ｌ　21/30	５２８
Ｇ０３Ｆ　7/20	５２１		Ｇ０３Ｆ　7/20	５２１
			Ｈ０１Ｌ　21/30	５１４Ｚ
				５１５Ｚ

審査請求　未請求　請求項の数23　ＯＬ　（全 13 頁）

(21)出願番号　特願平7－121115

(22)出願日　平成７年(1995)５月19日

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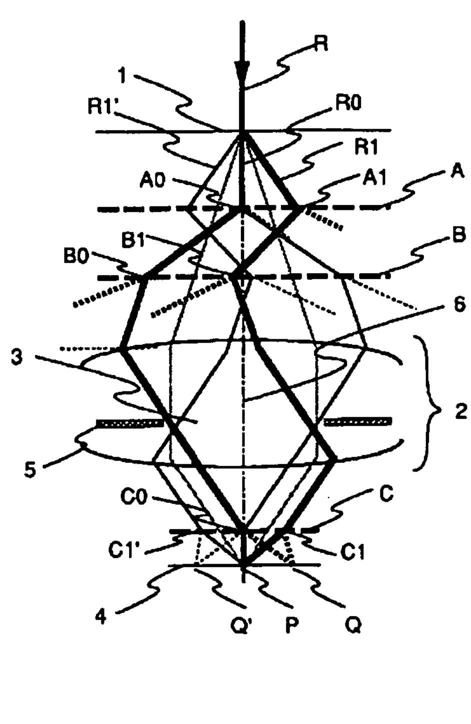
(54)【発明の名称】　投影露光方法及び露光装置

(57)【要約】
【構成】　マスク１を投影光学系２により基板４上へ投影露光する際、マスク１と投影光学系２の間に２枚の回折格子（Ａ，Ｂ）を、投影光学系と基板の間に１枚の回折格子Ｃを設け、これにより回折された光の干渉により基板面近傍でマスクパターンの像が再生されるようにした。
【効果】　従来露光装置の空間部分に回折格子を挿入するだけで、光学系のＮＡを実質的に最大２倍にした効果が得られる。このため、大きな露光フィールドを持ち大量生産に適した縮小投影光リソグラフィを用いて、寸法０．１μｍクラスのＬＳＩの製造が可能となる。

図１



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【特許請求の範囲】

【請求項１】マスクを準備する工程と、光源からの光を上記マスクに照射する工程と、
上記マスクのパターンを回折する工程と、
該回折した光を投影光学系を通して回折し試料上に上記マスクパターンを再生し露光する工程から成ることを特徴とする投影露光方法。

【請求項２】上記回折する工程として２回回折することを特徴とする請求項１記載の投影露光方法。

【請求項３】光源と、
該光源からの光でマスク上のパターンを照射し、該マスクからの光を回折する第１と第２の回折手段と、
回折した光を試料上に投影する投影光学系と、
該投影光学系からの光を回折する第３の回折手段と、
該第３の回折手段の下に配置された試料を載置する試料台からなることを特徴とする投影露光装置。

【請求項４】上記第１と第２の回折手段は位相格子であることを特徴とする請求項３記載の投影露光装置。

【請求項５】光源を発した波長λの光を照明光学系を介してマスクに照射し、上記マスク上のパターンを開口数ＮＡ、縮小率Ｍ：１の投影光学系により基板上へ結像させることにより上記基板上にパターンを形成する方法において、上記基板と上記投影光学系の間に上記基板と平行な第１の回折格子を有し、前記第１の回折格子により回折された光の干渉により基板面近傍でマスクパターンの像が再生されるように、上記マスクと上記照明光学系の間に、上記マスクと平行に、上記マスク側から順に第２の回折格子と第３の回折格子の２枚の回折格子を設けることを特徴とする投影露光方法。

【請求項６】前記回折格子を設けた光学系の遮断空間周波数ｆが、前記回折格子を設けない光学系の遮断空間周波数ｆ０より大きく、かつｆ０の２倍以下であることを特徴とする請求項５記載の投影露光方法。

【請求項７】前記第１の回折格子の空間周期Ｐ１は、
$\lambda/(1.42\cdot NA) \leqq P1 \leqq \lambda/NA$
の範囲にあることを特徴とする請求項５記載の投影露光方法。

【請求項８】上記第１、第２及び第３の回折格子の周期方向は等しく、上記第１の回折格子の空間周期Ｐ１、第２の回折格子の空間周期Ｐ２、第３の回折格子の空間周期Ｐ３は、ほぼ
$1/P3 = 1/P2 - 1/(M\cdot P1)$
の関係を満たすことを特徴とする請求項５記載の投影露光方法。

【請求項９】上記第１の回折格子の上記基板表面から光学距離Ｚ１、及び、上記第２、第３の回折格子の上記マスク表面から光学距離Ｚ２、Ｚ３は、ほぼ
$(Z3 - Z2)/P2 = (Z3/M + Z1\cdot M)/P1$
の関係を満たすことを特徴とする請求項５記載の投影露光方法。

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【請求項１０】上記第１の回折格子、上記第２の回折格子、及び上記第３の回折格子の各設置位置、上記第１の回折格子、上記第２の回折格子、及び上記第３の回折格子を設ける各透明基板の膜厚、及び上記第２の回折格子の周期を、前記投影光学系のＮＡ及び縮小倍率、各回折格子と上記基板の位置関係に応じて、上記マスク面と像面の間の収差が最小となるように設定したことを特徴とする請求項５記載の投影露光方法。

【請求項１１】前記第２の回折格子の空間周期Ｐ２は、
$P2 \leqq 1/(1 - 2\cdot NA/M)$
を満たすことを特徴とする請求項５記載の投影露光方法。

【請求項１２】前記第２及び第３の回折格子は、位相格子であることを特徴とする請求項５記載の投影露光方法。

【請求項１３】前記第１の回折格子は、位相格子であることを特徴とする請求項５記載の投影露光方法。

【請求項１４】前記基板と前記第１の回折格子の間に、前記一方向に対する幅がＺ１・ＮＡ以下で、空間周期がほぼ２・Ｚ１・ＮＡの第１の遮光パターンを設けるとともに、前記マスクの直上又は直下に、マスク上の上記第１の遮光パターンとほぼ共役な領域を遮光する第２の遮光パターンを設けて露光領域を制限するか、又は、上記制限された露光領域を基板上で走査して露光するか、もしくはステップ状に移動しながら露光することを特徴とする請求項５記載の投影露光方法。

【請求項１５】前記回折格子は１次元回折格子であり、前記投影光学系の波面収差が、瞳上での上記回折格子の周期方向と垂直な方向の直径を軸として、線対称となるように収差補正されていることを特徴とする請求項５記載の投影露光方法。

【請求項１６】前記マスクは、周期型位相シフトマスクを含むことを特徴とする請求項５記載の投影露光方法。

【請求項１７】前記マスクは、前記第１の回折格子の周期及び方向に応じて、特定方向に微細なパターンを有することを特徴とする請求項５記載の投影露光方法。

【請求項１８】前記マスクは、前記第１の回折格子の周期及び方向に応じて、パターン形状を補正したことを特徴とする請求項５記載の投影露光方法。

【請求項１９】前記第１の回折格子と前記基板の間を、屈折率ｎが１より大きい液体で満たし、前記投影光学系のＮＡを、
$0.5 < NA < n/2$
の範囲に設定したことを特徴とする請求項５記載の投影露光方法。

【請求項２０】光源を発した波長λの光をマスクステージ上のマスクに照射する照明光学系と上記マスク上のパターンを基板ステージ上の基板表面近傍で結像させる開口数ＮＡ、縮小率Ｍ：１の投影光学系を有する投影露光装置において、上記基板と上記投影光学系の間に上記基

板と平行な第１の空間周期Ｐ１（λ／（１.４２・ＮＡ）≦Ｐ１≦λ／ＮＡ）の第１回折格子を有し、上記第１の回折格子により回折された光の干渉により基板面近傍でマスクパターンの像が再生されるように、上記マスクと上記照明光学系の間に、上記マスクと平行に、上記マスク側から順に第２の回折格子と第３の回折格子の２枚の回折格子を有することを特徴とする投影露光装置。

【請求項２１】上記第１、第２及び第３の回折格子の周期方向は等しく、上記第１の回折格子の空間周期Ｐ１、第２の回折格子の空間周期Ｐ２、第３の回折格子の空間周期Ｐ３は、ほぼ

１／Ｐ３＝１／(Ｍ・Ｐ１)＋１／Ｐ２

の関係を満たすことを特徴とする請求項２０記載の投影露光装置。

【請求項２２】上記第１の回折格子、上記第２の回折格子、及び上記第３の回折格子の各設置位置、上記第１の回折格子、上記第２の回折格子、及び上記第３の回折格子を設ける各透明基板の膜厚、及び上記第２の回折格子の周期を、前記投影光学系のＮＡ及び縮小倍率、各回折格子と上記基板の位置関係に応じて、上記マスク面と像面の間の収差が最小となるように設定したことを特徴とする請求項２０記載の投影露光装置。

【請求項２３】前記基板と前記第１の回折格子の間に、前記一方向に対する幅がＺ１・ＮＡ以下で、空間周期がほぼ２・ＮＡ・Ｚ１の遮光パターンを有するか、又は、上記遮光パターンにより制限された露光領域を基板上で走査して露光するか、もしくはステップ状に移動しながら露光する機能を有することを特徴とする請求項２０記載の投影露光装置。

【発明の詳細な説明】

【０００１】

【産業上の利用分野】本発明は、各種固体素子の微細パターンを形成するためのパターン形成方法、及びこれに用いられる投影露光装置に関する。

【０００２】

【従来の技術】ＬＳＩ等の固体素子の集積度及び動作速度を向上するため、回路パターンの微細化が進んでいる。又、レーザー等の光・電子素子や各種の量子効果素子、誘電体・磁性体素子等の特性向上のため、パターンの微細化が望まれている。現在これらのパターン形成には、量産性と解像性能に優れた縮小投影露光法が広く用いられている。この方法の解像限界は露光波長に比例し投影レンズの開口数（ＮＡ）に反比例するため、短波長化と高ＮＡ化により解像限界の向上が行われてきた。

【０００３】又、縮小投影露光法の解像度をさらに向上するための手法として、位相シフト法、変形照明法（斜入射照明法）、瞳フィルター法等、様々な像改良法が適用されている。これらは、従来光学系の性能を理論的な回折限界（遮断空間周波数＝２ＮＡ／λ）ぎりぎりまで有効に使用しようというものである。これら像改良法

（しばしば超解像法と呼ばれる）については、例えば、ＵＬＳＩリソグラフィ技術の革新、第１章、第３４頁から第４９頁（サイエンスフォーラム社刊、１９９４年、東京）に論じられている。

【０００４】一方、顕微鏡の解像度を、従来の上記回折限界を越えて向上する方法として、光学系の空間周波数帯域を拡大する方法がいくつか知られている。これら空間周波数帯域拡大法については、例えば、応用物理、第３７巻、第９号、第８５３頁から第８５９頁（１９６８年）に論じられている。このうちの１つの方法は、２つの格子パターンを物体及び像の直上（少なくとも焦点深度内）で互いに共役関係を保ちつつスキャンするもので、物体とその直上の第１格子パターンの重ねあわせによりモアレパターンを形成し、このモアレパターンをレンズ系を通過させ、像側で第２の格子パターンと重ねることにより復調を行なう。モアレパターンは、物体及び第１格子パターンより低い空間周波数を有するため、レンズ系を通過することができる。この方法を縮小投影露光法に適用することが出願されている。一般に、ウエハー直上で格子パターンを機械的にスキャンするのは困難なため、ホトクロミック材料をウエハ上に直接設け、これに干渉縞を重ねてスキャンすることにより、格子として機能させている。

【０００５】

【発明が解決しようとする課題】しかしながら、上記様々な従来技術には次のような課題がある。

【０００６】まず露光光の短波長化は、光学（レンズ）材料の透過率の問題からＡｒＦエキシマレーザ（波長１９３ｎｍ）が限界と考えられる。又、レンズ設計及び製造上の問題から、投影光学系のＮＡは０.６～０.７が限界と考えられる。しかるに、従来露光法の解像限界は一般に０.５λ／ＮＡ、周期型位相シフト法を用いた場合は０.３λ／ＮＡ程度であり、従って、上記短波長化及び高ＮＡ化の限界を用いても、０.１μｍ以下のパターンは形成は難しい。又、上記周期型位相シフト法ではマスクパターンが制限されるため、より一般的な回路パターンに関して、実際の限界寸法はさらに後退する。又、ＬＳＩの大規模化に伴い露光面積の拡大が要求されているが、投影光学系の露光フィールドの拡大と高ＮＡ化の要求を同時に満足することは極めて困難となっている。

【０００７】一方、従来の回折限界を越えることを目的とする各種空間周波数帯域拡大法は顕微鏡を対象とし、微小な物体を拡大することを目的とする。このため、光リソグラフィで要求される微小な光学像を形成するのには必ずしも適してはいないという問題点があった。例えば、前記モアレパターンを利用する方法では、２つの格子をマスク及びウエハーの直上で互いに共役関係を保ちつつスキャンするための機構又は光学系が著しく複雑となる。レジストの露光が実質的にエバネッセント光で行われるため波長レンジで光が減衰して厚いレジストを露

光するのが困難となる等の問題がある。さらに、ホトクロミックを使用する場合でも適当な材料がない。従って、ＬＳＩの大量生産を考えた場合、必ずしも実用的とはいえないという問題点があった。

【０００８】本発明の目的は、各種固体素子の微細パターンを形成する投影露光法において、その解像度を、従来の回折限界（遮断空間周波数）を越えて向上する方法を提供することにある。具体的には、投影光学系のＮＡを変えることなしに、そのＮＡを実質的に最大２倍にしたのとほぼ同等の効果が得られる新規な投影露光方法と、これを可能とする露光装置を提供することにある。

【０００９】本発明の別の目的は、従来型の露光装置の構成と光学系を大きく変更することなく、これらに多少の改良を加えるだけで解像力向上効果の得ることが可能で、かつ大きな露光フィールドと高い解像力を同時に満足するＬＳＩの大量生産に適した投影露光方法を提供することにある。

【００１０】

【課題を解決するための手段】上記目的は、波長λの光を用いてマスクパターンをの投影光学系（開口数＝ＮＡ、縮小率＝１：Ｍ）により基板上へ結像させてパターンを形成する際、上記基板と上記投影光学系の間に、上記基板と平行に、空間周期Ｐ１（但し、λ／（１．４２・ＮＡ）≦Ｐ１≦λ／ＮＡであることが望ましい）の第１の回折格子を設けるとともに、上記第１の回折格子により回折された光の干渉により基板面近傍でマスクパターンの像が再生されるように、前記投影光学系と前記マスクの間に、上記マスクと平行に、上記マスク側から順に第２の回折格子と第３の回折格子の２枚の回折格子を設けることにより達成される。

【００１１】第１の回折格子の回折光によりマスクパターンの像を忠実に再生するためには、上記第１、第２及び第３の回折格子の周期方向は等しく、上記第１の回折格子の空間周期Ｐ１、第２の回折格子の空間周期Ｐ２、第３の回折格子の空間周期Ｐ３を、ほぼ１／Ｐ３＝１／Ｐ２－１／(Ｍ・Ｐ１)の関係を満たす様に設定する。又、上記第１の回折格子の上記基板表面からの光学距離Ｚ１、及び、上記第２、第３の回折格子の上記マスク表面からの光学距離Ｚ２、Ｚ３は、ほぼ

（Ｚ３－Ｚ２）／Ｐ２＝（Ｚ３／Ｍ＋Ｚ１・Ｍ）／Ｐ１

の関係を満たす様に設定する。さらに、Ｐ２≦１／（１－２・ＮＡ／Ｍ）であることが望ましい。又、第１、第２、第３の回折格子の設置位置、各回折格子の透明基板の膜厚、及び第２の回折格子の周期を、上記マスク面と像面の間の収差が最小となるように設定することが好ましい。又、基板と第１の回折格子の間に、幅がＺ１・ＮＡ以下で、空間周期がほぼ２・Ｚ１・ＮＡの第１の遮光パターンを、又、前記マスクの直上又は直下に上記第１の遮光パターンとほぼ共役な領域を遮光する第２の遮光パターンを設けて露光領域を制限することが好ましい。さらに、必要に応じて、上記制限された露光領域を基板上で走査して露光するか、もしくはステップ状に移動しながら露光することが好ましい。これら各回折格子は、位相格子であることが好ましい。

【００１２】なお、前記回折格子は１次元回折格子とし、前記投影光学系の波面収差を、瞳上での上記回折格子の周期方向と垂直な方向の直径を軸として、線対称となるように収差補正することが好ましい。又、本発明は、マスクとして周期型位相シフトマスクを用いた場合、特に大きな効果を発揮する。さらに、必要に応じて回折格子の周期及び方向に応じて、微細なパターンの周期や方向を制限したり、パターン形状を補正することが望ましい。又、第１の回折格子と前記基板の間を屈折率ｎが１より大きい液体で満たし、前記投影光学系のＮＡを、

０．５＜ＮＡ＜ｎ／２

の範囲に設定すると、さらに微細なパターンの形成が可能となる。

【００１３】

【作用】本発明は、投影光学系の最終エレメントとウエハの間に回折格子を設け、ウエハ面へ入射する光ビームの入射角を大きくすることにより、実効的にＮＡを増大するのと等価な効果を得ようというものである。しかし、単純に従来光学系のレンズ－ウエハ間に回折格子を設けただけでは、本来像面上の１点に集約するはずの回折光は、像面上のばらばらな位置に散らばってしまい、マスクパターンの再生は到底困難である。従って、干渉の結果元のマスクパターンに忠実な像が再生されるように、光学系を再構成する必要がある。しかも実用性の観点から、これらの光学系は、従来の投影光学系を大きく改造することなく、しかも従来のマスクが使用可能であることが好ましい。本発明は、以下述べるようにこれらの要求を満足するものである。

【００１４】本発明の作用を説明するために、本発明による結像の原理を従来法と比較して説明する。本発明の一形態に基づく光学系における結像を図１に、又比較のため、従来投影露光光学系で従来マスク又は位相シフトマスクを、各々垂直に照明した場合と斜めに照明した場合の結像の様子を図２ａ、ｂ、ｃ、ｄに示す。いずれの図でも、２：１縮小光学系とコヒーレント照明、１次元パターンを仮定し、近軸結像近似した。

【００１５】まず、従来光学系で通常マスクを垂直照明した場合（図２ａ）、透過型マスク２１に垂直入射した光２２はマスク上のパターンにより回折され、回折光のうち投影光学系２３の瞳２４（絞り２０の内側）を通過した光線が像面２５上に収斂し、干渉してパターンを形成する。ここで、瞳を通過できる最大の回折角を与えるパターン周期を解像限界と定義すると、解像限界は、λ／（２ＮＡ）（但しＮＡ＝ｓｉｎθ_0）となる。さらに、この光学系に周期型位相シフトマスク２６を適用す

ると、図２ｂに示したように０次回折光が消滅して光軸２９（図中一点鎖線）に対して対称に回折光が生じる。このため、瞳を通過できる最大の回折角は２倍となり、解像限界はλ／（４ＮＡ）まで向上する。
【００１６】又、従来光学系に斜め照明を適用すると（図２ｃ、簡単のためマスク回折光の０次光２７が図中瞳の左端を通過すると仮定した）、マスク回折光のうち０次光を中心として正負どちらかの回折角をもつ片側成分（図では＋１次光２８）だけが瞳を通過し、像面に収斂する。垂直入射の場合の２倍の回折角を有する回折光が瞳を通過できるため、解像限界はやはりλ／（４ＮＡ）となる。しかし、回折スペクトルの片側しか用いないため、例えば孤立パターンの解像度は垂直照明の場合と変わらず、又、周期パターンの場合でもコントラストが低下する等の問題がある。さらに、マスクを周期型位相シフトマスク２６に変更すると複数の回折光は瞳を通過できないため、パターンは解像しない（図２ｄ）。
【００１７】次に、本発明の一形態に基づく光学系における結像を図１に示す。図１の光学系は、図２の従来光学系において、マスク１と投影光学系２の間に回折格子Ａ及び回折格子Ｂを、又、投影光学系２とウエハー４の間に回折格子Ｃを挿入したものである。ここで、回折格子Ａ、Ｂ、Ｃはともに位相格子とする。
【００１８】マスク１に垂直入射した光Ｒはマスク面で０次回折光Ｒ０、＋１次回折光Ｒ１、－１次回折光Ｒ１’に回折される。０次光Ｒ０は回折格子Ａ上の点Ａ０に達し、そこで－１次方向に回折された光は、回折格子Ｂ上の点Ｂ０で＋１次方向に回折された後、瞳３（絞り５の内側）の左端を経て回折格子Ｃ上の点Ｃ０で±１次方向に回折され、各々像面上の２点Ｑ、Ｐに達する。又、＋１次回折光Ｒ１は、回折格子Ａ上の点Ａ１に達し、そこで－１次方向に回折された光は回折格子Ｂ上の点Ｂ１で＋１次方向に回折された後、瞳３の右端を経て回折格子Ｃ上の点Ｃ１で±１次方向に回折され、やはり像面上の点Ｑ、Ｐに達する。一方、点Ａ０で＋１次方向に回折された０次光Ｒ０’と－１次回折光Ｒ１’に対する光路は、上述の２光線の光路と光軸６（図中一点鎖線）に対して対称となる。即ち、両者は、最終的に回折格子Ｃ上の点Ｃ０で±１次方向に回折され像面上の点Ｐ、Ｑ’に達する。従って、Ｐ点ではマスクで回折された０次光、及び＋１次、－１次光線の３つの光線が交わる。このことが、マスク回折角に依らないのは明らかである。従って、点Ｐでは回折像が忠実に再生される。
【００１９】従来法（図２ａ）と比べると、同一のＮＡ、倍率を持つ光学系を用いて、２倍の回折角をもつ回折光が瞳を通過できるため、実質的にＮＡを２倍したのと同様の効果が得られる。又、斜め照明（図２ｂ）では０次光を中心として正負どちらか片方の回折光しか像面で再生できないのに対して、本発明では両側の回折光を像面で再生できるため、斜め照明では困難であった孤立パターンの解像度向上が可能で、また周期パターンに対して大きなコントラストを得ることができる。さらに、本光学系に周期型位相シフトマスクを適用すると（図３ａ）、０次回折光が消滅して通常の倍の回折角を有する＋１次光Ｒ＋と－１次光Ｒ－が干渉する結果、最小解像度はλ／（８ＮＡ）となる。これは、これまで周期型位相シフトマスクや斜め照明を用いた場合の理論限界であるλ／（４ＮＡ）の半分であり、本発明により飛躍的な解像度の向上が可能となる。また、本光学系において斜め照明を適用した場合の結像の様子を図３ｂに示す。斜め照明により、片側のみに対して大きな回折角をもつ回折光Ｒ１”まで瞳を通過させることが可能となり、垂直照明時の最大２倍、即ちλ／（８ＮＡ）まで解像度を向上できる。又、マスク入射角の異なる様々な照明光を用いれば、従来光学系におけるのと全く同様に部分コヒーレント照明の効果を得ることができる。
【００２０】本発明の原理をフーリエ回折理論の立場から説明すると次のようになる（図４）。以下の説明では、光学系の倍率は１、回折格子は１次元位相格子で±１次回折光のみを考えるものとする。像面上の点Ｐから、回折格子Ｃを介して瞳３を見ると、回折により瞳は２つに分かれて見える（図４ａ）。各瞳の中には、各々ある特定の角度で瞳を通過するマスクフーリエ変換像が見える。一方、マスク側について考えると、マスクにより回折された光は回折格子Ａ及びＢで回折されて、瞳上に複数のマスクフーリエ変換像を形成する。このうち、ある特定の角度で瞳を通過したものが、上で見えた瞳の中に見えることになる（図４ｂ）。即ち、図４の場合、図４ｂの右のフーリエ回折像が図４ａの左側の瞳の中に見え、図４ｂの左のフーリエ回折像が図４ａの右側の瞳の中に見える。このとき、点Ｐで正しく像が再生されるための条件は次の２点である。
【００２１】（１）２つの瞳を介してマスク上の同一点のスペクトルが見えること。
【００２２】（２）２つのスペクトルが、２つの瞳の接点で連続して接続すること。
【００２３】言い替えれば、１つの連続するスペクトルを複数の瞳を介して見ることができるようにする必要がある。
【００２４】像から見て、回折格子Ｃを介してｆ’シフトした複数の瞳が見え、その各瞳の中に回折格子Ｂ及びＡを介してやはりｆ”シフトした複数のフーリエ回折像が見えるとすると、真の像の振幅分布ｕ(ｘ)は次式で表わされる。
【００２５】
$$u(x)=F[\Sigma p(f-f')\cdot\Sigma o(f-f'')]$$
$$f'=\pm SC$$
$$f''=\pm(SA-SB-SC)$$
ここで、Ｆ[ ]はフーリエ変換、ｐ(ｆ)は瞳関数、ｏ(ｆ)はマスクフーリエ回折像、ｘは実空間座標、ｆは空

間周波数座標、ＳＡ、ＳＢ、ＳＣは回折格子Ａ、Ｂ、Ｃの回折角のsin（正弦）、Σは異なる回折次数に対する和を表す。従って、

ＳＡ＝ＳＢ＋ＳＣ

とすると、

ｆ”＝０

となり、ｆ’＝±ＳＣの両方に対して共にｆ”＝０となる項を得ることができる。即ち２つの瞳ｐ(ｆ±ＳＣ)を介して１つのスペクトルｏ(ｆ)を見ることができる。さらに、点Ｐでマスク上同一点に対する像を得るためには、マスク面と回折格子Ａ、Ｂ間の距離、及び回折格子Ｃと理想像面間の距離、各々ＺＡ、ＺＢ、ＺＣを、

ＳＡ·(ＺＢ－ＺＡ)＝ＳＣ·(ＺＢ＋ＺＣ)

とすればよい。

【００２６】上の条件を近軸近似の下で縮小率Ｍ：１、像側開口数ＮＡの光学系に適用すると、回折格子Ａ、Ｂ、Ｃの周期ＰＡ、ＰＢ、ＰＣ、マスク面と回折格子Ａ、Ｂ間の距離ＺＡ、ＺＢ、回折格子Ｃと理想像面間の距離ＺＣをほぼ次のように設定すればよいことがわかる。

【００２７】１／ＰＡ=１／ＰＢ－１／(Ｍ·ＰＣ)

(ＺＢ－ＺＡ)／ＰＡ=(ＺＢ／Ｍ＋Ｍ·ＺＣ)／ＰＣ

さらに、本発明により十分な解像度向上効果を得るためには、

λ／ＮＡ≦ＰＣ≦√２·λ／ＮＡ

とすることが好ましい。

【００２８】回折格子Ａ、Ｂは、位相格子であることが好ましい。回折格子Ａ、Ｂが完全な位相格子でなく０次光を透過する場合、本方法より解像性に劣る従来光学系や斜入射光学系等の効果が本方法の効果に重なる。このため解像性が劣化する恐れがある。一方、回折格子Ｃは位相変調格子であっても振幅強度変調格子であっても構わない。回折格子Ｃの周期はかなり小さく、屈折率１．５のシリコン酸化膜を考えると格子パターンの断面縦横比はほぼ１程度となる。この場合、パターン断面での光の散乱効果に注意する必要がある。遮光パターンからなる回折格子の場合、遮光膜の厚さはかなり薄くできるため散乱の影響は低減できる。但し、後で述べるように、位相変調格子を用いる方が露光領域を広くすることができる。

【００２９】回折格子Ｂの基板側を屈折率ｎが１より大きい液体等で満たすと、この領域の波長と回折角のｓｉｎが１／ｎとなる。そこで、さらに回折格子Ｂの周期を細かくし、回折角を液体を満たさない場合と等しくすると、波長だけが１／ｎとなるため解像度も１／ｎに向上する。この場合、マスク側ではより回折角の大きな回折光が瞳を通過できる様マスク照明角を増大させる必要があるが、このとき回折角の小さな回折光は瞳を通過できなくなる。そこで、瞳の径をこれに応じて増大することが望ましい。このことは次のように言い替えることもできる。回折格子Ｂと基板の間の屈折率が１の場合、本発明で用いる投影光学系のＮＡを０．５以上にしても何ら解像度向上は得られない。sinθ＞０．５の角度θで周期λ／ＮＡの回折格子Ｂに入射する光線に対する回折角は９０度以上となり、エバネッセント波として回折格子表面に局在化してウエハーには伝わらないためである。一方、回折格子Ｂと基板の間の屈折率をｎとすると、sinθ＝ＮＡの角度で回折格子Ｂ（瞳の端を通過した０次光がウエハーに垂直入射するためには周期λ／ＮＡでなければならない）へ入射した光の回折角θ’は

sinθ’＝（λ／ＰＢ+sinθ）／ｎ＝２ＮＡ／ｎ

となり、θ’＜９０度であるための条件は、ＮＡ＜ｎ／２となる。即ち、本発明を最大ＮＡ＝ｎ／２の光学系まで有効に適用できる。一般に液浸光学系は特別な光学設計を必要とするが、上述の様に本発明に適用した場合には何ら特別のレンズを必要としない。従って、半導体プロセスにおいて通常使用されているＮＡ０．６程度の投影レンズを用いて、回折格子Ｂと基板の間を水（屈折率約１．３）で満たして露光すれば、実質的にＮＡを１．２としたのと等価な効果が得られる。この場合、位相シフトマスクを用いれば、水銀ランプのｉ線の波長（３６５ｎｍ）でも、０．１μm以下の解像度が得られることになる。なお、本方法では、ウエハー近傍で干渉する光の入射角は極めて大きいため、結像性能は光の偏光状態に強く依存する。一般に、電場ベクトルが光の入射面に垂直な偏光状態を有する光の方が、高いコントラストの像を形成する上で望ましい。

【００３０】以上の議論は全て近軸近似を仮定し、回折格子の基板の屈折率を１としたものであり、実際には回折格子の基板の屈折率の効果や、回折格子により生じる収差の影響を厳密に考慮する必要がある。このため、各回折格子の設置位置等は若干変更する場合がある。複数の回折格子のパターンの周期方向は十分な精度で一致させることが好ましいことはいうまでもない。

【００３１】次に、本発明において注意すべき点について４点述べる。

【００３２】第１に、本光学系では従来露光法と比べて、一般に露光領域が制限される。図１より分かるように、像面上の点Ｑ、Ｑ’においても２光線が交わり互いに干渉して像が形成される。この像は、本来形成されるべきでない位置に生じる偽の像であり、一般に好ましくない。これを回避するため、図５ａに示すように像面５１の直上（ウエハーと回折格子Ｃの間）に遮光マスク５２を設けてこれらの偽の像を遮断することが望ましい。回折格子Ｃと遮光マスク５２は、図に示したように同一の石英基板５３の両面に形成することができる。（別々の基板上に形成しても構わない。）又、これと同時に同様にして、マスクの直上又は直下に上記遮光マスクとほぼ共役な領域を遮光するマスキングブレードを設ける等して、マスク照明領域を上記共役な領域に制限することが好ましい。１回の露光で転写可能な露光領域は、真の

像（P点）と偽の像（Q点）の間の距離（ほぼ2・NA・ZB）に相当する領域で、上記距離の２倍を周期として繰返し現れる。従って、露光可能な領域が露光したい面積より狭い場合には、図５ｂに示した様に、露光領域をウエハー上でスキャンすることが望ましい。この際、光学系の縮小率がM：１であったならば、マスクスキャン速度とウェハースキャン速度の比も厳密にM：１とすることが望ましいことはいうまでもない。これら露光領域をマスク及びウェハー上で同期スキャンする方法に関しては、既存の露光装置で用いられている方法をそのまま用いることができる。一方、露光可能領域が露光したい面積より大きい場合、即ち、真の像と偽の像の間の距離が例えば１個のチップをカバーする場合には、スキャンせずに露光可能である。露光領域の大きさは回折格子Ｂの設置位置によって決まり、回折格子Ｂを像面から離すほど、１つの露光領域の幅は増大する。但し、同時に転写不可能な領域の幅も増大するため、両者の割合はほぼ１：１のまま変わらない。偽の像の影響を排除するために、ウエハー上露光領域の幅Wは、W≦NA・ZBとすることが望ましい。又、回折格子Ｂに振幅強度変調格子を用いた場合には、格子の０次回折光が真の像と偽の像の中間点にもう一つの偽の像を形成するため、露光領域は位相格子の場合のほぼ半分となる。

【００３３】第２に、本方法では一般に露光強度が低下する。本方法でウェハー上で結像する光線は、光学系中に挿入された回折格子により回折された光線のうち特定の回折次数の光だけを用いている。従って、回折格子を通過する度に露光に寄与する光強度は低下することになる。また、上で述べたようにマスク及びウェハー上で露光領域を制限していることも、スループット低下の原因となる。このため、本方法では十分に強度の強い光源を用いる、感度の高い化学増幅系レジスト等のレジスト材料を用いる等の対策を行うことが望ましい。

【００３４】第３に、前の説明で示したように、瞳上には、f”＝０の望ましい回折像に加えて、f”＝±２(SA＋SB)だけシフトしたフーリエ変換像が生じる。これは、マスクパターンの高次スペクトルが実質的に低い空間周波数領域に重なってしまうことを意味し、一般に好ましくない。図１の光学系においてこれを避けるためには、

PA≦１／（１－２・NA／M）

とすればよい。この場合、マスクで回折角２・NA／Mで回折された回折光（図１中R１）に対する回折格子Aによる＋１次方向の回折光（図１中A１から発する点線に相当）は存在できないからである。

【００３５】第４に、本発明の光学系では、回折格子導入に伴う収差に注意する必要がある。回折格子により発生する収差について、図６を用いて説明する。マスク通過後の光線が光軸と回折格子の周期方向を含む面内にあると仮定する（例えば、１次元パターンとコヒーレント照明）。図６ａの光学系が無収差であるためには、例えば$OX_1X_2X_3I$、$OY_1Y_2Y_3I$、及び$OZ_1Z_2Z_3I$の各光路長の差が０でなければならない。しかし、これらの間に光路長差があるとこれが収差となる。ここで投影光学系は収差０の理想的な光学系であると仮定すると、$X_2X_3=Y_2Y_3=Z_2Z_3$より、$OX_1X_2+X_3I$、$OY_1Y_2+Y_3I$、及び$OZ_1Z_2+Z_3I$の差が収差となる。瞳の直径を横切る$OX_1X_2X_3I$から$OZ_1Z_2Z_3I$に至る光路の波面収差を$OY_1Y_2Y_3I$を基準として規格化した瞳半径座標ｓに対してプロットすると図６ｂの実線のようになる。マスク通過後光軸に対して＋の角度を有する光線に対する収差ｗ＋(ｓ)は瞳上で一般に非対称となることがわかる。同様に光軸に対して－の角度を有する光線に対する収差ｗ－(ｓ)は、光学系の対称性からｗ＋(ｓ)と瞳を中心として対称となる。本発明では、＋方向に回折した光と－方向に回折した光を同時にウエハー上で干渉させる必要があるから、両者に対する収差を同時に補正する必要がある。しかし、図６ｂからわかるように、＋方向と－方向に回折した光に対する瞳上収差が一致しないことから、これらを同時に投影光学系で補正することは原理的に困難となる。従って、これらの収差は、マスクと投影光学系の間、又はウエハーと基板の間で補正することが好ましい。これは、一般に次のような方法で行うことができる。

【００３６】ｗ＋(ｓ)とｗ－(ｓ)が等しければ、これを投影光学系で補正することが可能である。そこで、$\Delta w(s)=\{w+(s)\}-\{w-(s)\}$ を、瞳上（図６では$-1\leqq s\leqq 1$の範囲）で波長と比べて十分に小さい量δに抑えればよい。一方、$\Delta w\pm(s)$は、各回折格子の設置位置と周期、回折格子を支える基板の厚さと屈折率、基板と回折格子の相対位置関係等のパラメータx_i（$i=1$、２、…）の関数として表される。そこで、問題は、$-1\leqq s\leqq 1$の範囲で、$\Delta w(s, x_i)<\delta$を満たすx_iを求めることに帰着する。実際の最適化の例については実施例で述べる。いずれにせよ、このようにして、マスク通過後光軸に対して±の角度を有する光線に対する収差を瞳上で対称な形とすれば、これを投影光学系において補正することができる。又、さらに上で述べた方法により収差自体を十分に抑制することができれば、より好ましい。

【００３７】以上、簡単のためマスクパターンとして１次元のパターンを想定したが、実際には２次元パターンが存在したり、部分コヒーレント照明を用いた場合には、マスク通過後の光線は、光軸と回折格子の周期方向を含む面内に収まらず、瞳上の様々な点に向かう。この場合、Δｗとして、瞳上の２次元座標（ｓ、ｔ）の関数$\Delta w(s, t)=\{w+(s, t)\}-\{w-(s, t)\}$ を考え、瞳面内で、$\Delta w(s, t, x_i)<\delta$を満たす$x_i$を求めればよい。これは、$w\pm(s, t)$を瞳上で$s=0$に対してできるだけ対称な形とすることを意味する。

【0038】さらに、全ての方向に対して本発明の効果を得るためには、例えば図7a、bに示すように各回折格子を2次元回折格子とすることが考えられる。この場合、見かけ上の瞳の形は4回対称となる。しかしながら、上で述べた事情により、互いに垂直な2組の瞳に対して瞳上で同時に収差補正することは、光学系のＮＡが小さい場合を除いてやや困難である。このため、マスク上ですべての方向に対して同等に本発明の効果を得ることはやや難しく、図8のような1次元回折格子を用いるのがより現実的である。図8a、b、cは3つの代表的な回折格子と見かけ上の瞳形状である。図8aの場合、ｘ方向のパターンに対して実質的なＮＡは2倍近く増大するが、ｙ方向のパターンに対しては減少する。図8bの場合、ｘ方向のパターンに対して実質的なＮＡは√2倍となり、ｙ方向のパターンに対しては1／√2となる。図8cの場合、ｘ，ｙ両方向ともＮＡは√2倍となるが、ｘ，ｙ方向以外に対する結像性能は著しくパターン方向に依存すると考えられる。何れの場合にも、マスク上でパターンのレイアウトルール等に方向による制限を課すことが望ましい。

【0039】結像性能のパターン方向依存性をなくすためには、図8a、b、cの条件を、各々例えば90度回転させて多重露光を行ってもよい。特に、図8cにこれを適用した場合には、ｘ，ｙ方向以外に対するパターン方向依存性を抑制し、かつ像コントラストを犠牲とせずにｘ，ｙ両方向ともＮＡを√2倍したのと同等な像を得ることができる。但し、回折格子を90度回転させた場合、収差特性も90度回転する。そこで、収差補正を瞳フィルターを用いて行い、回折格子とともにこれを90度回転させる等の対策を施すことが望ましい。なお、収差抑制が困難な場合には、必要に応じて瞳にスリットフィルターを設ける等してもよい。

【0040】図3に示したように周期型位相シフトマスクを完全コヒーレント照明した場合には、ウエハー近傍で干渉する±1次光の光路は光軸に対して常に対称であり、各々の光路長は等しい。従って、光学系が収差補正されていなくても微細パターン形成可能である。即ち、完全コヒーレント照明下で周期型位相シフトマスクを用いる場合には、図7に示したような2次元回折格子が使用可能で、位相シフトマスクの効果をパターン方向に依らず最大限に発揮することができる。様々なパターンの混在するマスクパターンを転写する場合には、微細周期パターンのみを上記方法で露光し、その後その他の部分を従来露光法で露光すればよい。

【0041】また、上記収差は一般にＮＡの値とともに急激に増大する。このため、ＮＡ0.1～0.2程度の光学系では比較的問題とならない。従って、低ＮＡ・低倍率の大面積用露光装置や、反射型の軟Ｘ線縮小投影露光装置等に適用する場合には、上で述べたような様々な制約が軽減される。

【0042】以上、本発明は、0次回折光線を中心としたフーリエ回折像の左右片側を各々別々に瞳を通過させ、これを像側で合成するものであるといえる。この考え方自体は、前述の文献に論じられている様に既に光学顕微鏡に応用されているものであるが、これを縮小投影光学系の上で実現可能な光学系の構成はこれまで考案されていなかった。本発明は、これを縮小投影露光系においてたくみに実現したものに他ならない。即ち、図1の光学系は、投影光学系とウエハの間に回折格子を設け、ウエハ面へ入射する光ビームの入射角を大きくするとともに、ウエハ面干渉の結果元のマスクパターンに忠実な像が再生されるように、光学系を構成したものである。本発明は、屈折光学系、反射光学系、及びこれらの組合せ、縮小光学系、等倍光学系等、様々な投影光学系に適用できる。これらの光学系を用いてマスクパターンをウェハー上へ露光する場合の露光方法としても、一括転写、スキャン方式、ステップアンドリピート、ステップアンドスキャン等のいずれにも適用可能である。又、以上の説明より明らかなように、本発明は純粋に幾何光学的な効果に基づいている。従って、前述のモアレ縞を用いる方法における様なエバネッセント光利用に起因する問題点は生じない。又、回折格子はウエハーより離して設置可能で、しかも同期スキャン等の必要もないため、はるかに容易に実現可能である。

【0043】

【実施例】

（実施例1）本発明に基づき、ＮＡ＝0．45、光源波長λ＝248nm、縮小率4：1のスキャン型ＫｒＦエキシマレーザ投影露光装置を、図9に模式的に示すように改造した。即ち、マスクステージ100上に設置したマスク101と投影光学系102の間に、両面に位相格子パターンを有する透明石英板103を挿入した。又、ウエハーステージ（試料台）104上に設置したウエハー105と投影光学系102の間に、片面に遮光パターン、もう片面に位相格子パターンを有する透明石英板106を、遮光パターンの側がウエハーに対面するように挿入した。遮光パターンは幅300μm周期1mmのＣｒパターン、位相格子パターンは周期＝λ／ＮＡのＳｉ酸化膜パターンとした。マスク側透明石英板103上の位相格子パターンの周期は、ウエハー側の4倍である。Ｓｉ酸化膜厚は、膜の存在部と存在しない部分を透過した光の位相が180度ずれるように設定した。これらのパターンはＥＢリソグラフィを用いて、いわゆるクロムレス位相シフトマスクの作製プロセスと同様にして形成した。又、マスクの照明光学系107側に、幅1.2mm、周期＝4mmの遮光パターンを有する透明石英板108を設けた。上記遮光パターンの遮光領域は、ウエハー側透明石英板106上の遮光パターンと共役となるように設定した。

【0044】透明石英板103両面の位相格子の周期、

各透明石英板の膜厚と設置位置等は、作用の項に述べた意味における投影光学系瞳上の収差が軸対称となるよう、光線追跡プログラムの最適化機能を用いて最適化した。さらに、上記軸対称な収差補正のため、収差補正フィルター１０９を投影光学系の瞳位置に挿入した。ここで、収差補正フィルター１０９は、主に上記回折格子の周期方向と垂直な方向の非点収差を補正するものである。なお、これらの回折格子等を有する透明石英板と収差補正フィルターは、いずれも交換可能で、所定の位置にすみやかに設定できるようにした。又、透明石英板の位置ぎめを正確に行うために、各石英基板のホルダー（図示せず）は微動機構（図示せず）を有し、各石英基板の位置を計測してこれを所望の位置に設定することができる。さらに、ウエハーステージ１０４上に設けたオートフォーカスモニター（図示せず）により像をモニターすることにより、像面上で最適な結像特性が得られるように、モニター結果をフィードバックして各石英基板の位置を調整することも可能とした。なお、投影光学系自体をあらかじめ上記回折格子に対して収差補正を施してもよく、この場合には収差補正フィルターは必要ない。露光は、マスク及びウエハーを同期スキャンしながら行なった。ステージ制御系１１０は、マスクステージ１００とウエハーステージ１０４を、各々４：１の速度比で同期走査する。

【００４５】上記露光装置を用いて、周期型位相シフトパターンを含む様々な寸法のパターンを有するマスクを、化学増幅系ポジ型レジスト上へ転写した。露光後所＊定の現像処理を行い、走査型電子線顕微鏡で観察した結果、上記位相格子の周期方向（ｘ方向）に対して周期型位相シフトマスクにより寸法９０ｎｍ（周期１８０ｎｍ）のレジストパターンが形成できた。一方、上記方向と垂直な方向（ｙ方向）の解像度は、位相シフトマスクを用いて寸法１４０ｎｍ（周期２８０ｎｍ）程度であった。そこで、次に、上記３枚の位相格子及び収差補正フィルターを９０度回転して同じマスクを露光してレジストパターンを形成したところ、ｘ方向とｙ方向に対する解像度は逆転した。

【００４６】なお、上の実施例は、光学系の種類、ＮＡ、光源波長、縮小率、レジスト、マスクパターンの種類と寸法、回折格子と遮光パターンの周期や設置位置等、きわめて限定されたものであるが、これらの各種条件は本発明の主旨に反しない範囲内で様々に変更可能である。

【００４７】（実施例２）次に、回折格子導入に伴う収差の影響が最小となるよう、光学系を最適化した例を示す。図１０の光学系において、Ｏ、Ｉは、回折格子を導入した光学系のマスク面と像面、Σ、Σ'は回折格子を導入しない投影光学系のマスク面と像面、ｈｉ（ｉ＝１～６）は図中の距離を示す。回折格子Ａ、Ｂ、Ｃとウエハー直上の遮光パターンは実施例１同様透明石英基板の両面に形成した。このとき、マスク通過後に光軸に対して±の角度を有する光線に対する横収差ｗ±(ｓ)は、規格化瞳半径座標ｓの関数として次のように表される。

【００４８】

$$w\pm(s)=wu\pm(s)+ws\pm(s)$$
$$wu\pm(s)=C_1h_1+C_2(s_1)h_2+C_5h_5+C_6h_6$$
$$ws\pm(s)=C_3h_3+C_4h_4$$
$$C_1=\tan[(s\pm s_0)/M]/M,\ C_2=\tan[\pm(s_1/n)-(s\pm s_0)/(nM)]/M,$$
$$C_3=\tan[s/M]/M,\ C_4=\tan(s),$$
$$C_5=\tan[(s\pm s_0)/n],\ C_6=\tan(s\pm s_0)$$

ここで、ｗｕは瞳上でｓ＝０に対して非対称な成分、ｗｓは対称な成分を表す。但し、s_0＝ＮＡ、s_1＝λ／ＰＡである。s_0（ＮＡ）、縮小倍率Ｍ、透明石英基板の屈折率ｎはシステム固有の値とすると、上式は７つの最適化パラメータ、ｈｉ（ｉ＝１～６）及びs_1を含む。そこで、ｗｕ±(ｓ)、ｗｓ±(ｓ)に対して収差を最小とすべく７つの拘束条件を課すことにより、これらの値を最適化した。いくつかのＮＡに対する最適化結果の一例を表１に示す。但し、収差はh_5／λを単位とする波面収差で表した。

【００４９】

【表１】

表１

NA	0.1	0.2	0.3	0.4
h_1/h_5	17.352	16.167	14.263	11.343
h_2/h_5	0.529	0.995	1.343	1.507
h_3/h_5	24.014	22.800	20.137	14.819
h_4/h_5	0.368	0.485	0.652	0.920
h_6/h_5	0.01	0.01	0.01	0.01
s1	1.225	1.259	1.300	1.349
$w_{max}(s)$	5×10^{-9}	3×10^{-7}	4×10^{-6}	5×10^{-6}
$w^u_{max}(s)$	1×10^{-12}	1×10^{-9}	2×10^{-7}	1×10^{-5}

$$w^u_{max}(s) = \max[w+(s) - w-(s)]$$
$$s1 = n\lambda/PA$$

【００５０】表からわかるように、ＮＡ＝０．４においても十分に収差を抑えることが可能であった。同様の最適化は、回折格子Ａ、Ｂが各々別の透明基板上に設けられている場合等、様々な配置に対して行うことができる。さらに、新たな透明基板や回折格子を導入することにより最適化のパラメータを増やすことにより、さらに厳しい収差条件を満足させることができる。

【００５１】（実施例３）次に、実施例１に示した露光装置を用いて、０．１μm設計ルールのＤＲＡＭを作成した例について述べる。図１１は、上記デバイスの作製工程を露光プロセスを中心に示したものである。

【００５２】まず、ウエル等（図示せず）を形成したＳｉ基板２０１上にアイソレーション２０２及びゲート２０３を形成した（図１１ａ）。アイソレーション及びゲートパターンは周期型位相シフトマスクを用い、実施例１に示した露光装置により露光した。ここで、シミュレーションにより周期パターンの周辺部においてパターン形状が歪む部分が生じることが予測されたため、この不要部分を除去するためのマスクを用意した。上記マスクを上記露光を行ったものと同一レジスト膜に対して従来露光装置を用いて重ね露光した後現像して、回路性能上好ましくない部分を除去した。なお、上記不要部分を除去せずに、回路的に無視することによって対処してもよい。

【００５３】次に、キャパシター２０４及びコンタクトホール２０５を形成した（図１１ｂ）。コンタクトホールのパターン露光には、電子線直接描画法を用いた。次に、第１層配線２０６、スルーホール（図示せず）、第２層配線２０７を形成した（図１１ｃ）。第１層配線（０．１μmＬ／Ｓ）は周期型位相シフトマスクと実施例１に示した露光装置を用いて露光した。但し、ここで各回折格子の方向と寸法を図９ｃに示したものに変更し、さらにこれを９０度回転させて多重露光を行った。このとき、同時に収差補正フィルター１０９も回折格子とともに９０度回転させた。これにより、縦横の両方向に延びる配線に対して方向依存性なしに０．１μmＬ／Ｓを形成できた。スルーホールの形成はコンタクトホールと同様、電子線直接描画法を用いた。以降の多層配線パターン及びファイナルパッシベーションパターンは０．２μmルールで設計されており、本発明を用いない通常のＫｒＦエキシマレーザ投影露光法により形成した。なお、デバイスの構造、材料等に関し、上記実施例で用いたものにとらわれず変更可能である。

【００５４】（実施例４）次に、本発明の別の実施例として、本発明を分布帰還型（ＤＦＢ）レーザーの製作に適用した例について述べる。露光装置には、ＮＡ０．５のＡｒＦエキシマレーザ縮小投影露光装置を実施例１同様にして改造したものを用いた。従来の１／４波長シフトＤＦＢレーザーの作製工程において、電子線描画法等を用いて形成していた周期１４０ｎmの回折格子を、周期型位相シフトマスクと上記露光装置を用いて形成した。これにより、電子線描画法等を用いて作製したものとほぼ同等の性能を有するＤＦＢレーザーを、より短期間で製作することが可能となった。

【００５５】

【発明の効果】以上、本発明によれば、照明光学系を介して光をマスクに照射し、マスクパターンを投影光学系により基板上へ結像させてパターンを形成する際、上記基板と上記投影光学系の間に上記基板と平行に回折格子を設けるとともに、上記回折格子により回折された光の干渉により基板面近傍でマスクパターンの像が再生されるように、投影光学系とマスクの間又はマスクと照明光学系の間に回折格子又は結像光学系を設けることにより、従来露光装置の解像限界を越えた微細パターンの形成が可能となる。具体的には、投影光学系のＮＡを変えることなしに、そのＮＡを実質的に最大２倍にしたのとほぼ同等の効果が得られる。これにより、従来露光装置の光学系の基本的な構成を大きく変更することなく、大きな露光フィールドと高い解像力が得られ、大量生産に適した縮小投影光リソグラフィを用いて、寸法０．１μmクラスのＬＳＩの製造が可能となる。

【００５６】

【図面の簡単な説明】

【図１】本発明による一光学系の結像の原理を幾何学的に示す模式図である。

【図２】各種従来露光法による結像の原理を示す模式図である。

【図３】本発明による一光学系に位相シフトマスク又は斜め照明法を適用した場合の結像の原理を示す模式図である。

【図４】本発明による一光学系の結像の原理を回折光学的に示す模式図である。

【図５】本発明による一光学系の一部分と露光方法の一例を示す模式図である。

【図６】本発明による一光学系の特性を示す模式図である。

【図７】本発明で用いる光学部品とそれにより得られる効果を示す模式図である。

【図８】本発明で用いる光学部品とそれにより得られる効果を示す模式図である。

【図９】本発明の一実施例による露光装置の構成を示す模式図である。

【図１０】本発明の別の実施例の特性を示す図である。

【図１１】本発明の別の実施例によるデバイス作製工程を示す模式図である。

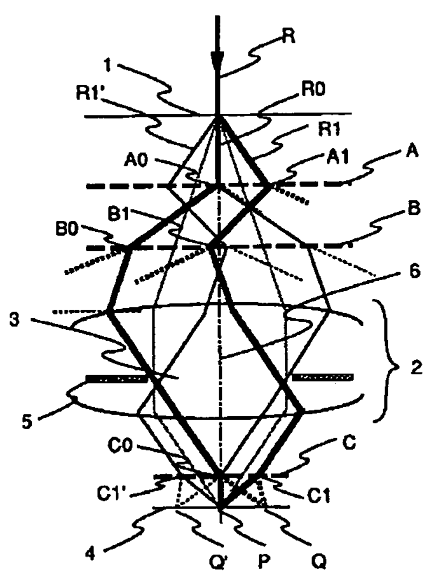
【符号の説明】

１…マスク、２…投影光学系、３…瞳、４…ウエハー、５、２０…絞り、６、２９…光軸、Ａ、Ｂ、Ｃ…回折格子、Ｒ…光、Ｒ０、Ｒ０’…０次回折光、Ｒ１、Ｒ＋、Ｒ１”…＋１次回折光、Ｒ１’、Ｒ－…－１次回折光、

Ａ０、Ａ１…回折格子Ａ上の点、Ｂ０、Ｂ１…回折格子Ｂ上の点、Ｃ０、Ｃ１、Ｃ１’…回折格子Ｃ上の点、Ｑ、Ｐ、Ｑ’…像面上の点、２１…従来透過型マスク、２２…光、２３…投影光学系、２４…瞳、２５…像面、２６…周期型位相シフトマスク、２７…マスク回折光の０次光、２８…＋１次光、５１…像面、５２…遮光マスク、５３…石英基板、Ｏ…マスク上の点、X_1、Y_1、Z_1…回折格子Ａ上の点、X_2、Y_2、Z_2…回折格子Ｂ上の点、X_3、Y_3、Z_3…回折格子Ｃ上の点、Ｉ…像面上の＊点、１００…マスクステージ、１０１…マスク、１０２…投影光学系、１０３…透明石英板、１０４…ウエハーステージ（試料台）、１０５…ウエハー、１０６…透明石英板、１０７…照明光学系、１０８…透明石英板、１０９…収差補正フィルター、１１０…ステージ制御系、２０１…Ｓｉ基板、２０２…アイソレーション、２０３…ゲート、２０４…キャパシター、２０５…コンタクトホール、２０６…第１層配線、２０７…第２層配線。

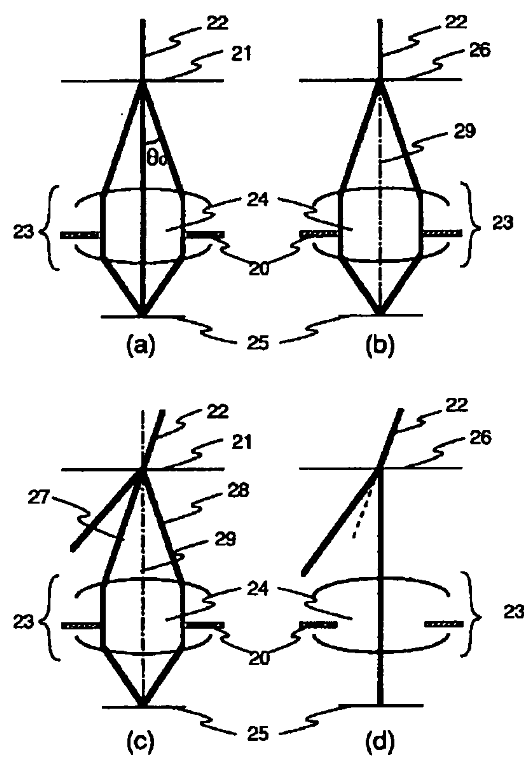
【図１】

図１



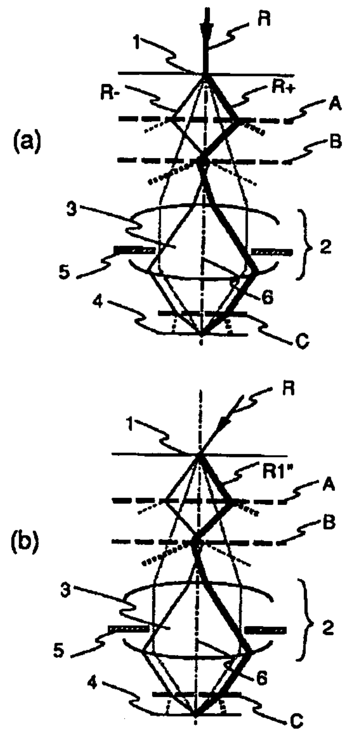
【図２】

図２



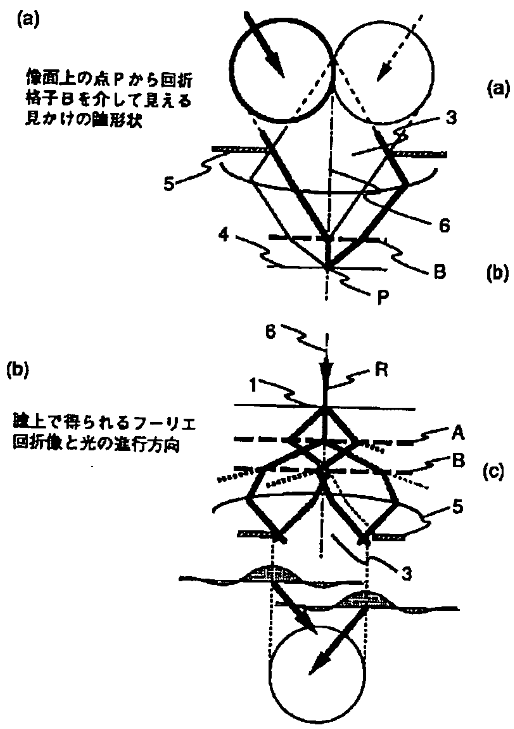
【図3】

図3



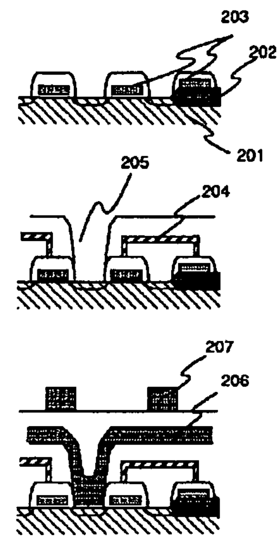
【図4】

図4



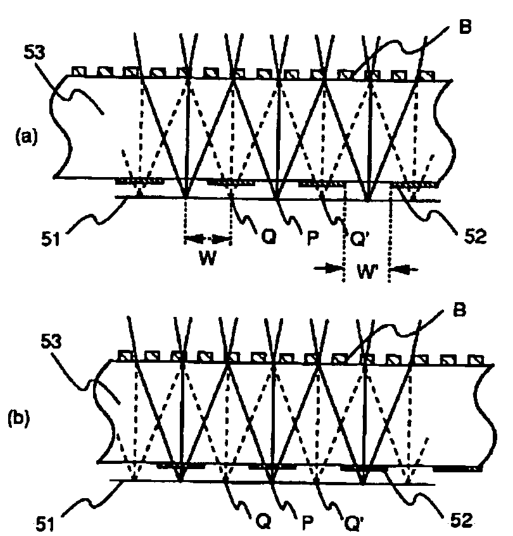
【図１１】

図１１



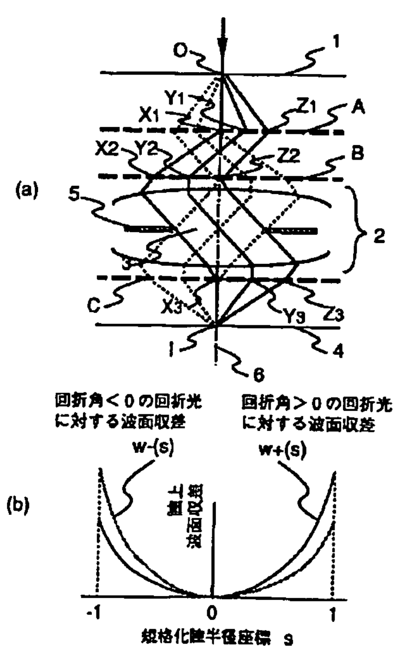
【図5】

図5



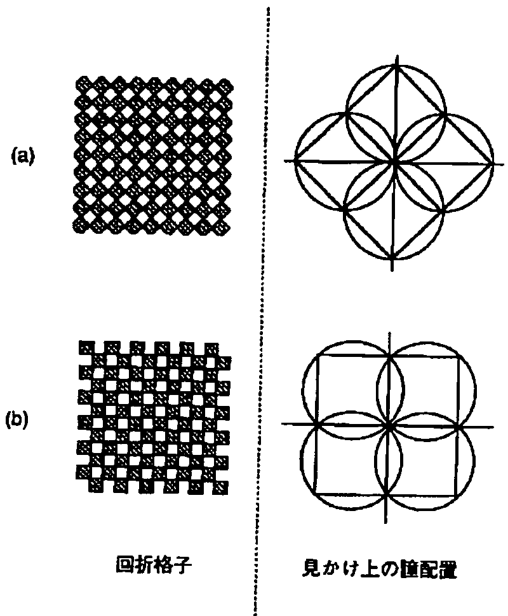
【図6】

図6



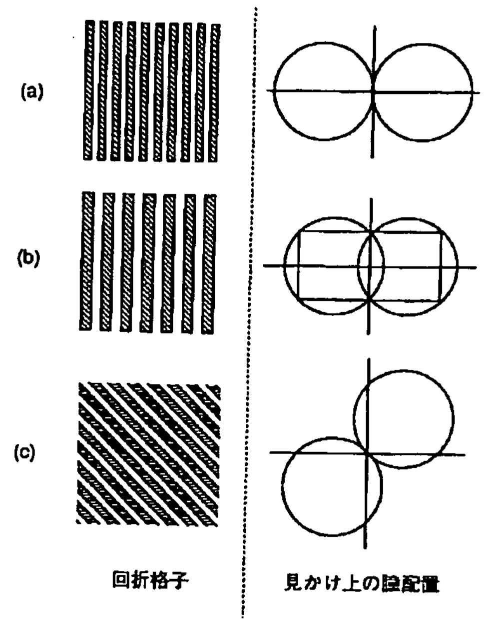
【図7】

図7



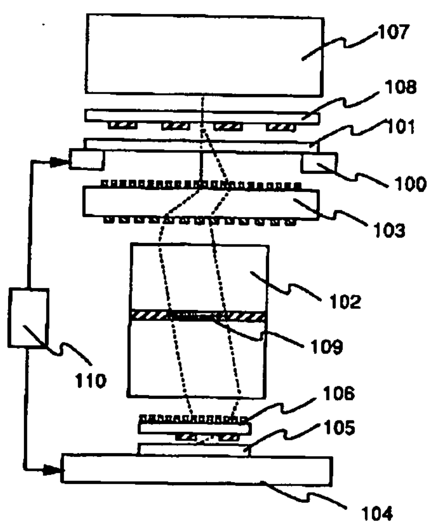
【図8】

図8



【図9】

図9



【図10】

図10